ELECTRICITY
AND ITS SOURCE

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BY

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CONTENTS

CHAPTER		PAGE
I.	OBJECT OF THE BOOK	1
II.	THE VOLTAIC CELL: VOLTAIC ELECTRICITY	3
III.	CHEMICAL ACTION IN THE CELL: VOLTAIC ELECTRICITY	11
IV.	THEORIES OF ELECTROLYSIS, AND ACTION AT THE ANODE: VOLTAIC ELECTRICITY	20
V.	THE CURRENT AND ITS EFFECTS: VOLTAIC ELECTRICITY	31
VI.	THE VOLTAIC PILE AND ELECTRODEPOSITION: VOLTAIC ELECTRICITY	39
VII.	THE ELECTRICAL MACHINE: STATIC ELECTRICITY	46
VIII.	THE CHEMICAL ACTION: STATIC ELECTRICITY	54
IX.	ACTION OF HEAT AND CURRENT ON JUNCTIONS: THERMOELECTRICITY	62
X.	CHEMICAL ACTION: THERMOELECTRICITY	69
XI.	CONDUCTION THROUGH GASES	77
XII.	CONDUCTION BY LIQUIDS AND SOLIDS	87
XIII.	ELECTROLYTIC SURFACE CONDUCTION	94
XIV.	NONCONDUCTORS	102
XV.	ELECTRICAL RESISTANCE IS THE OPPOSITION BY CONDUCTORS TO THE ELECTRIC CURRENT	110
XVI.	ELECTRIC WIND AND GLOW DISCHARGE	119
XVII.	BRUSH AND SPARK DISCHARGES	128
XVIII.	CHEMICAL ACTION OF DISCHARGE	135
XIX.	ACTION OF INFLUENCE	144
XX.	INFLUENCE IS AN ÆTHER WAVE	151
XXI.	INFLUENCE AND INDUCTION	156
XXII.	THE ACTION OF INDUCTION	162
XXIII.	THE PRODUCTION OF INDUCTION	171
XXIV.	ELECTROLYSIS NOT STORAGE	179

CHAPTER		PAGE
XXV.	CONVECTION AN INTERRUPTED CONDUCTION	187
XXVI.	ELECTRICITY CAUSES A MOTION OF MATERIAL	193
XXVII.	FLUID IS THE CONDUCTOR ON SOLID CONDUCTORS: ELECTRICITY	206
XXVIII.	INFLUENCE: ELECTRICITY	212
XXIX.	TWO ELECTRICITIES	220
XXX.	THE RAY DESCRIBED	230
XXXI.	HERTZIAN RAYS	239
XXXII.	RÖNTGEN AND OTHER RAYS	246
XXXIII.	ATMOSPHERIC ELECTRICITY	256
XXXIV.	DESCRIPTIVE: THE AURORA	264
XXXV.	DEDUCTIONS: THE AURORA	275
XXXVI.	NATURAL GLOW DISCHARGE: ST. ELMO'S FIRE	281
XXXVII.	NATURAL GLOW DISCHARGE: FIREBALLS	287
XXXVIII.	PRODUCTION: LIGHTNING	296
XXXIX.	EFFECT: LIGHTNING	305
XL.	INSTANCES AND DEDUCTIONS: ANIMAL ELECTRICITY	311
XLI.	COMETS: COMETS' TAILS	317
XLII.	COMETS' TAILS	325
XLIII.	APPENDIX	336

INTRODUCTORY

CHAPTER I

OBJECT OF THE BOOK

WHAT is electricity? The object of the book is to answer this question—if we can.

One or two books have already been written with this avowed object, but have got no further than to dogmatize on a pet theory supported by some effects produced by electricity.

As electricity is only known by its effects, it is right to describe its actions, and the mistake made by the authors of those books was, the working from an uncertain top of theory downwards, instead of from a secure base of facts upwards.

It is only by allowing ourselves to be led by facts that we can come to a true decision, and we are certainly more likely to do so if we enter on the subject with our minds quite free from any prejudices, and judge entirely by the evidence given by experiment. We must, in fact, act in the manner in which juries are supposed to act, and look upon theories as special pleadings tending to divert our minds from the true verdict. "Enter if you can without preconceived notions, listen to nothing that the facts cannot establish, and deny yourself the luxury of any theory at all. Then you may succeed where authority fails." This was written with reference to investigation of crime, but it is equally applicable to any investigation. Charles Darwin is usually supposed to have begun his work with his theory,

but it was not so, for he himself says that he started "without any theory and collected facts in a wholesale way," and we cannot do better than follow his very notable example.

For clearness of examination we must group the actions of electricity, so we will divide the subject into sections to be studied separately, and we will not come to any decision on the main question till we have gone through all the sections. In one or two places the writer has forgotten this good intention, and has made deductions that further consideration has shown to be wrong: they have been left to show the unwisdom of premature conclusion, and must not be taken as the final word.

Confirmatory extracts from the works of scientists are given to show that the author is supported in what he says by well-known men, and these extracts are marked "thus."

The author begs his readers to read the text as though it was a series of lectures to an experimenting class in which he and they are co-students. This will allow of a little more freedom and simplicity of speech, with less of that dry-as-dustiness and stilted tone so constantly found in scientific works.

Neither magnetism nor electrodynamics will form any part of our study; therefore, as these are used in nearly all *practical* work, the book is not likely to interest the man whose interest in science is merely pecuniary.

Current is only a part of electricity, but current is so commonly used for electricity that probably it will be often found used in that sense in this book.

VOLTAIC ELECTRICITY

CHAPTER II

THE VOLTAIC CELL

We will begin our study of electricity by examining the phenomenon of its production in the voltaic cell. When we have finished with this, we will go on to other modes of production, and we will keep each branch of the subject separate, and pick out from each its reliable results, and when we have finished with all, we will assemble our results and see whether they may form a basis for a sensible and incontrovertible explanation.

To understand the principle of the voltaic cell it will be best to take it, to begin with, in its simplest form, which is a vessel, three-fourths full of acidulated water, in which two metal plates are suspended separately and facing one another: each plate has a wire soldered to its upper end, and the junctions of the wires and plates, and the wires for an inch or two above the junctions, are coated with shellac varnish to protect them from the action of the acid in the water.

The plates must be of dissimilar metals, for the action of the cell depends on the chemical activity of the one metal, and the resistance to change of the other, and the greater the difference the stronger the cell. This difference is named difference of potential, and the more potent or powerful metal is the one that more weakly dissolves away.

It is easy to show that two dissimilar metals are required, for two similar pieces—say of zinc—arranged in the cell, in place of the usual pieces of zinc and copper, will be equally corroded, but will give no current: and neither will two

pieces of any metal that is not acted on—such as platinum—give any current.

When a piece of common commercial zinc is put in water, mixed with some sulphuric acid, we see that the zinc becomes corroded and that bubbles of gas are set free at its surfaces; and this gas, if collected and examined, is found to be hydrogen. This hydrogen must come from the water, as that is the only substance present in which there is any of it. Chemically, the substances we have used are zinc, sulphuric acid, which is composed of one part of sulphur and three of oxygen, and water composed of two parts of hydrogen and one of oxygen. Or in chemical symbols, $Zn + SO_3 + H_2O$. The sulphuric acid and the oxygen of the water attack the zinc and produce sulphate of zinc, and the hydrogen goes free. Or in symbols the result is $ZnSO_4 + H_2$. It is a somewhat slow process, and some chemists say that the zinc is attacked by the acid because of an electrical action set up by minute bits of impurities, mostly iron, scattered through it, and that perfectly pure zinc would not be corroded, in which case there would be no change and no hydrogen set free.

However this may be, as perfectly pure zinc is difficult to get, it is the general practice to prevent this local action by amalgamating the zinc, which is done in the following way. After washing the zinc with dilute sulphuric acid, a few drops of mercury are rubbed on its surfaces with a bit of rag tied to a stick: the mercury dissolves the surfaces: and if the amalgamated zinc is now put into the acid and water, there is no action until the wires from the zinc and copper are joined: the zinc is then again corroded, and as fast as it is dissolved away in the amalgamated surface, the mercury dissolves a fresh layer of the plate. The impurities either dissolve or fall to the bottom.

The reason why the zinc is preserved by the amalgamation in one instance and not in the other, is that the chemical

union of the zinc and mercury of the amalgamated plate is strong enough to resist the action of the sulphuric acid and oxygen of the water, until these are assisted by some force that begins to act on joining the circuit of the wires.

To show better the effect of completing the circuit by joining the wires, we will use ordinary unamalgamated zinc. Putting the zinc in the cell, we see the hydrogen bubbles rising from its surface. Now if we put in a copper plate and join the wire from the zinc to the wire from the copper, we see that there is some immediate change: that the zinc is more quickly corroded, and that the hydrogen instead of coming from its surface, comes from the surface of the copper. We remove the plates and examine them: the zinc is corroded and the copper unchanged.

It is quite clear from this, that in addition to the chemical union of the zinc, acid, and oxygen, and the consequent decomposition of the water, which would ordinarily occur, that the joining of the wires produces a movement that traverses the water between the plates, and that by this movement the hydrogen of the water is liberated at the copper.

When we bring the two wires together, we see a small bright spark at the point of junction, and if instead of bringing the two wires directly together we join them with a short bit of fine platinum wire, the wire will become hot, and if very fine may become white hot and consume away. Evidently the action in the cell causes some power to traverse the wires as well as the water.

This power has been found to be electricity.

In the voltaic cell it is an electricity which in its action resembles a broad and placid river whose current is ample but mild: in fact, so different from the electricity of the lightning, or of the electrical machine, that at first it was thought to be a different power: but their only difference is in what is called their electromotive force. The current of the electrical machine has little volume but much of this

force, and a rapid succession of long sparks can be kept up by working the machine: while the current of the cell has volume but little force, and Mr. DelaRue, with a battery of eleven thousand cells, could only obtain from it a spark somewhat less than two-thirds of an inch long.

The current of electricity circulates through the cell and the wires, and it has, until lately, been accepted that it flows from the zinc, through the fluid in the cell to the copper, and thence by the wires to the zinc again. At present there is an idea that the current flows in the opposite direction: and also it has been supposed that there is a double current, positive in the direction zinc to copper, and negative in the other direction, and the reason for this supposition is because the components of the fluid in the cell (which is called the electrolyte) are deposited, some on one plate of the cell and some on the other: but as these theories introduce unnecessary complications where practical work is concerned, and the explanations of most of the electrical phenomena of the voltaic cell are satisfactorily given on the zinc-to-copper positive current theory, we need not discuss these matters further at present.

The electrolyte is the acidified water, or other fluid, in the cell. The zinc is positive in the cell, according to the theory we are using, and is called the "anode," or entering road: and the copper is negative and is called the "kathode," or leaving road of the current.

If the ends of the wires from the copper and zinc be put in a liquid in a tube, or other vessel, the end of the wire from the copper kathode of the cell becomes the anode in the new arrangement, and the end of the wire from the zinc anode becomes the new kathode. The point of entry of the positive current is the anode, and of its exit the kathode, in every case.

Whichever way the current may go it passes through the cell, so let us examine a working cell carefully. We

replace the plates joined by their wires: the action starts again and hydrogen bubbles gather on the copper: but in whatever way we may look through the water of the cell, in sunlight, or by artificial light, with magnifiers or without, our eyes can detect no movement except the up and down currents caused by the rise of the hydrogen bubbles and the fall of the dissolved sulphate of zinc.

Let us now try as an experiment the decomposition of water. For this we require the electricity of more than one cell, because the resistance of water to decomposition by electricity is greater than the force furnished by one cell can overcome. Until there is enough force to decompose the water it acts as a non-conductor and will not allow the current to pass. Measured by electrical notation the resistance of the water is 1·47 volts, while the force supplied by a Daniell's cell is 1·1 volts. One cell therefore is not strong enough, two are enough, but five will show the action more strongly: we connect them together by joining the wire from the copper of one cell to the wire from the zinc of the next, by which arrangement the force is increased just as many times as there are cells joined together in this way. Taking then some pure water and placing in it two platinum plates an inch apart, one of which we connect with the free copper wire of our battery, and the other with the free zinc wire, we see an action start at once, and from the plate joined to the wire of the copper electrode bubbles of oxygen are given off, and from that joined to the zinc electrode wire come bubbles of hydrogen. And if we collect these gases we find that there are about two parts by measure of hydrogen to one of oxygen, which we know is the proportion in which they are combined to form water; and they can be tested by burning the hydrogen, and by putting a smouldering match into the oxygen, when the match will burst into flame.

There is no commotion in the water nor any sign of any

bubbles anywhere except at the surfaces of the plates, and yet one constituent of the water is appearing free at one plate and the other at the other plate. There can be only one reasonable interpretation of what is happening, and that is, that the molecules of hydrogen and oxygen are separating at the surfaces of the plates and that in the water between they are merely changing partners: the hydrogen going one way, the oxygen the other, each transferred but never wholly free till they arrive at the ends of the lines. This in the main was the theory propounded by Grotthuss a hundred years ago, and which has since been mishandled in various ways. The only mistake Grotthuss made was in supposing that the molecules required arrangement before they could interchange components.

The molecule of water is compounded of two molecules of hydrogen and one of oxygen, and the weight of the oxygen molecule is eight times that of the two hydrogen molecules: the three are not mixed together to form a water molecule but are joined as bubbles are joined, and the heavy oxygen component always hangs below the lighter hydrogen. So these liquid molecules require no arranging to bring them into the proper position for work, as they are always in position. "Chemical combination is not so much a fusion or intermingling of the combining atomic structures, as rather an arrangement of them alongside one another under steady cohesive affinity."

The length of the diameter of the water molecule is perhaps a hundred millionth of an inch: so in every cubic inch of the water that we are experimenting with, there are a billion billions arranged in lines of a hundred millions, with the first and last molecule of each line touching the platinum plates: and all the molecules in each line are simultaneously interchanging components with a steady flow of oxygen towards the anode, and of hydrogen to the kathode.

It has been found that a few drops of sulphuric acid assist the decomposition of the water: but as none of the acid has been found decomposed by the current, it probably acts as what is called a catalyst, which is a substance, that by interfering in some way, helps other substances to part or combine without itself undergoing any change, or to put it more correctly, that it can, at the end of the action, be recovered quite unchanged, and that no metamorphosis is known to have happened to it. As these are points that have no material bearing on electricity, we may, for the purpose of explanation, accept the reasonable theory which supposes that in this case the acid and water molecules temporarily combine: $H_2O + SO_3$ become H_2SO_4: and in this form the electromotive force can more easily disengage the hydrogen and oxygen of the compound molecules.

The platinum plates when taken out and examined are found to be quite unchanged. In the cell we found that a chemical change must occur on one of the plates to produce a current, and here we find that the current, when once it is established, can reproduce chemical change when it passes through water. Further, it has been found that when the amounts of the changes in each action are measured they are found to be equal in amount. This is one of Faraday's discoveries.

If we could see what is taking place in the pure water when a current is passing through it, we should see an action going on in which there are no distracting complications, and Mr. Whetham has almost enabled us to do this: he placed a coloured and a colourless solution so that they met in a narrow part of a tube arrangement, and on sending a current of electricity through the liquids, the colour crept along the tube, though at the very slow rate of about an inch in three hours. This is extremely slow, but we must remember that these things that are moving are molecules: particles so small that a mass of a thousand of them together

could not be detected by the strongest microscope. The impulses of the current move every one of the millions of molecules in the line between the electrodes, but each impulse only moves each molecule one molecule's breadth, so though the succession of impulses may be quick, the rate of travel they produce must be slow.

From what we have learnt in this chapter we may deduce two facts. First, that it is plain that whatever may be happening in a working cell, the happening is due entirely and absolutely to action in the cell and has nothing to do with external influences: that in fact the apparatus is making electricity in itself. And secondly, that whether the corrosion of the zinc before joining the wires produces electricity or does not, we are not cognizant of any electric current in the apparatus until the wires are joined: that in fact the current depends on a particular arrangement of the apparatus.

Do not let us forget these facts.

VOLTAIC ELECTRICITY

CHAPTER III

CHEMICAL ACTION IN THE CELL

WE found when we began this enquiry that electrodes of similar metals did not produce a current, but we must add as a rider to this rule, that they must be under exactly similar conditions. For if we can increase the corrosion of one of two similar electrodes, or prevent or lessen the action on the other similar one, we can produce a current, because we have produced a difference of potential. A couple of examples will be sufficient to show this.

Get a **U**-shaped tube and nearly fill it with dilute nitric acid. Put the ends of a silver wire, one end into each end of the tube, and dip them one inch each into the fluid: there is no current, though the silver is being acted on, because the action is equal at both ends of the wire. Push one end of the wire three inches into the liquid, and immediately a current is established, and the less submerged wire is no longer acted on.

Take out the wire and pour a little more nitric acid into one end of the tube, and put in the wire ends to an equal depth at each end: a current is set up because of the greater action by the stronger liquid on one end of the wire.

So long as there is a difference of potential, that is a difference of chemical action, no matter how it is produced by the electrolyte, there is a current between the electrodes.

To detect the current, place the conducting wire on the glass of a pocket compass so that the wire is in line with the needle, and when a current passes the needle will be deflected. The compass acts better if the glass is removed.

The Emperor Napoleon III. invented a one metal cell: both electrodes were of copper, one in a solution of cyanide of potassium, the other in dilute sulphuric acid, and separated by a porous partition. There have been several other cells of this sort made, but as they are neither powerful nor economical, they can only be looked on as curiosities and are not of practical value.

We find in all elementary books on electricity lists of electropositive and electronegative elements, but except in the matter of cell construction, there is no need to consider their differences of potential further than to understand that their position on the list depends on the greater or less susceptibility to chemical change in association with oxygen which each one bears to the next on the list. Another list might be made of the elements in their chemical relation to chlorine, and so on: and every one of the substances can be made, as shown above in the case of silver, at once electropositive and electronegative to itself.

Both the zinc and the copper are acted on by the acid in the cell when the wires are not joined; but when the circuit is completed, the corrosion of the copper is suppressed, because the acid and oxygen move towards the zinc and only the hydrogen can reach the copper, on which it has no action.

In this common cell that we have been using, the hydrogen forms in little bubbles on the copper and coats it. The action of the cell is very much and very quickly weakened through this, and it is then said to be polarized. The gas, being an undecomposable element, is a nonconductor of electricity, and it prevents some of the current from reaching the copper: also the gas, immediately after its decomposition from water, is more oxidizable than the zinc, and sets up a current in opposition to the zinc current. Thus the hydrogen acts injuriously in two ways; and the electromotive force may be so lowered that the polarization current

may become as strong as the direct current and stop it. Various remedies have been devised to overcome this: such as sweeping the copper surface, or blowing the gas away with air: taking up the hydrogen by some combining substance in the electrolyte, such as chlorine or chromate of potash: or, which is much the best, preventing the gas from getting to the copper by putting a porous partition between the electrodes.

Something, however, must be deposited on the copper: some chemical action must run through the electrolyte the whole way from the anode to the kathode, or the cell does not work. The copper need not be acted on in any way chemically: the hydrogen bubbles have no such action on the copper and no affinity with it, and merely adhere to it consequent on the impulse of the current in that direction, and their own feeble attraction of cohesion: but action in the electrolyte must extend the whole way across between the electrodes. A plate of heated zinc and a plate of platinum joined by a wire and put in a jar of oxygen, give no current, although the zinc combines with the gas, because there is no action in the medium between the metals: the intervening gas is an element and is not decomposable, and therefore carries no current. If the plates were placed in a mixture of gases, the action of the gases on the zinc would probably set up a current combining them (perhaps with explosion) in the space between the plates, and the arrangement would then act like an ordinary cell. But without compoundable substances between the plates no electricity can be produced in a cell.

The fact that there is no current between the electrodal plates in oxygen in the experiment mentioned above, has been spoken of as a proof that chemical decomposition as well as chemical composition must occur in the working cell: but this does not follow, for electricity can be carried by chemical combination acting alone. An electric spark

will pass through a mixture of hydrogen and oxgyen, and is able to do so because of their combination into water. In air, the lightning flash passes because it compounds the mixed oxygen and nitrogen of the air. And the flash discharge can be forced through oxygen, which is an element and is not decomposable, but is compounded, with the help of the electromotive force, into its triad ozone. Therefore we may conclude that chemical composition is necessary to carry the current, and also that composition alone is *necessary.*

It follows as a corollary to the theory of Grotthuss, that no substance can pass from one electrode to the other unless it is combined with some other substance which passes in the opposite direction: and if we mix any powdered element in the electrolyte, whether the powder be metallic or otherwise, such as "pulverized charcoal, sublimed sulphur, spongy platinum, or precipitated gold, though they are in such small particles that they remain suspended in the fluid for hours and are perfectly free to move if impelled to either pole, they show no tendency unless they are brought into relation by chemical affinity with some other substance present in the fluid." This is true except that an elementary molecule can, in some few instances, combine with others of its own sort, as in the case of oxygen, which combines in threes to form ozone.

Molecules that are already combined travel by separation and recombination to the electrodes, but either or both of their components may be stopped by secondary combination, provided always, that they transfer their action to another set of molecules so that it may be carried forward by them. The working of a cell with a porous partition depends on this, and a description of a Daniell's cell will explain this better than any mere theoretic talk.

The outer cell of the Daniell, which acts as kathode, is a little copper pail, and is filled with saturated solution

of sulphate of copper, which is kept at full strength by crystals of the salt placed in a perforated trough round the cell inside near the top. The inner cell is of porous earthenware, and has in it a dilute acidified solution of sulphate of zinc, and an anode of amalgamated zinc, and the only precaution needed for this part is to see that the solution does not become saturated. The acid of the sulphate of zinc solution with the oxygen of the water together attack the zinc, and produce sulphate of zinc which is dissolved as fast as it is made, and the hydrogen from the water is deposited on the porous cell. The current produced on the zinc by the chemical action passes to the porous partition, where it meets the sulphate of copper solution, and preferring to work on the copper salt to working on the water it is dissolved in, it separates the copper from its oxygen and acid and deposits the metal on the kathode: the oxygen from the copper passes through the porous partition with the free acid and removes the hydrogen as fast as it collects there. The copper deposited on the copper cell can of course do it no harm, and the Daniell is therefore very constant, being free from any resistance except that of the working of the electrolytes in themselves.

The reason why the current should prefer the copper salt, as a carrier, to the water it is dissolved in, has not apparently, so far, been explained: but it has been found that, in a mixture of substances, those elements that are least prone to oxidation are those that the current chooses to separate and deposit first. Free copper is found in many parts of the world, so we may consider that it is not easily oxidized, and as it is easily extracted from its ores, that it is also easily dissociated from oxygen: free iron has been found in a thin vein in America, and associated with other minerals in meteorites, but it may be said to be very rare; it is very prone to oxidation, and is difficult of separation from oxygen: and hydrogen, though it is everywhere

present with us in its oxidized form as water, is conspicuous by its absence in a free state from our entire system, excepting the atmosphere of the sun. We judge from this that the elements vary in their hold on oxygen: that the cohesion between the molecules in some compounds is weaker than in others: that fewer impulses of the current are needed to free the copper than the hydrogen from oxygen: and we might add, that the current evidently takes the easier way, and that if the easier way substance is not sufficient for its wants, that it will fill up the gaps in the chains of molecules by using those of the next easier substance.

The presence of hydrogen in the atmosphere of the sun is a proof, if any is wanted, that no chemical action occurs in the sun, and as a consequence that there is no electricity in the sun. The sun cannot send out electricity because, as we are apparently beginning to find out, combination of material is necessary to its production. Therefore as this hydrogen, which with us is a most obstinately associating material, is found in the sun free, it is most unlikely that any other substances should be chemically combined there, and that therefore, so far as we know, that no electricity can be produced there.

A certain author writes as follows: "The light of the electric furnace is due to the combustion of carbon. There is carbon in the sun. Therefore the sun is an electric furnace." But it does not do to jump to conclusions quite so rapidly. We might with equal plausibility say the light of a tallow candle is due to the combustion of carbon, therefore the sun is a tallow candle. There is no carbon, but only carbon vapour in the sun. Carbon sublimes without melting at about 3500° C., and is therefore a gas at a temperature much below that of the sun. All the sun's constituents are excited far beyond chemical combination; so there is neither burning of carbon nor electricity in the sun.

Sir Humphry Davy proposed to use the action of preference for the protection of the copper sheathing of ships: using small pieces of iron, distributed at intervals, to take up the corrosion due to the chlorine in sea water, and so save the copper. So far as the preservation of the copper went, it was a success: the iron was corroded and the copper saved: but it was a failure commercially. The barnacles and seaweeds collected on the clean copper of the protected ships and lessened their speed of sailing, while the oxychloride on the unprotected copper of the other ships kept them comparatively clean: and the loss of time was more expensive than the loss of copper.

It is perhaps unnecessary to give any further explanation of the action in a cell with a porous partition, but it is well that it should be very clearly understood, and the description should be studied carefully.

The only use of the original sulphate of zinc in the solution is to prevent the copper solution from passing through the porous cell by osmosis.

As the electrolytic action must pass over the whole distance between the electrodes, and do the same amount of chemical action in each solution that it passes through, the energy of a cell is not increased by preventing polarization, it is merely prevented from decreasing. By keeping the kathode clean, the whole of the electrolyte between that surface and the anode is filled with lines of current: but if any part of the anode or kathode is covered, the action opposite that part is stopped. The only advantage therefore of oxidizing the hydrogen in Daniell's cell is that the cell suffers no loss of activity.

What is called osmosis, is the passage of fluids, with or without salts in solution, through the pores of substances such as unglazed earthenware, skin, parchment-paper, and such like. In the herring-curing places, when there was a tax on salt, they used osmosis to save salt, and perhaps

they do so still. Liquids with salts in solution will pass through the porous material, but not any of the substances that preponderate in animals and which from their likeness to glue are called colloids, not even when they are in solution. The dirty salt used for curing the herrings and the offal mixed with it were put, with a little water, in a parchment bag, and the bag into a tub of water, and in a short time the water in the tub acquired most of the salt, and then this water only needed boiling to recover the salt clean.

The following is a pretty experiment that anyone, even a non-smoker, can do if he has a little gold to spare. Break the stem off a new clay pipe, and plug the hole in the bowl: then fill the bowl with nitric acid and put it in a wine-glass in which are some hydrochloric acid and a piece of gold leaf. The leaf will be immediately consumed if touched with the end of a loop of gold wire, the other end of which is in the nitric acid. Now gold is not soluble in either of these acids alone but is so in the two mixed, and the result is not nitrohydrochloride of gold but simply chloride of gold. Nitric acid, hydrochloric acid, and gold, $HNO_3 + 3HCl + Au$, become nitric acid, hydrogen, and chloride of gold, $HNO_3 + 3H + AuCl_3$. The nitric acid acts as a catalyst and is found unchanged at the last. Probably by its superior attraction for hydrogen it loosens the cohesion of the hydrogen and chlorine in the hydrochloric acid and leaves the chlorine more free to attack the gold. In this experiment the porousness of the bowl is necessary, for without it there is no action. The action is started by some of the nitric acid creeping by osmosis through the bowl, or perhaps by some that oozed through when we filled it, and a few of its molecules have set up a very slight chemical combination with the gold leaf before the wire comes into play. Once the current is started, the chlorine pours upon the gold leaf and soon consumes it, because the excess of

potential is all on the hydrochloric acid side as the nitric acid has no action on the other end of the gold wire.

"Solutions of electrolytes exhibit chemical activity in the highest degree, because they are of the substances whose molecules are most easily discombined by either force (electrical or chemical). Also electrical force can assist chemical force to results that by itself it cannot attain." Nevertheless the two forces are in opposition to one another in electrolysis. If we examine the electrolyte for change produced in it by the current, we find none except perhaps the addition of some salt by the chemical corrosion of the anode. In the case of pure water we find that there is merely less water: and in saline solutions that there is a weakening of the solution: but otherwise there is absolutely no change of composition. The element that can combine with the anode goes towards it, and that which cannot goes the other way: there is interchange between the molecules in the liquid, but no sign that chemical action has set any of them free: and yet there may have been violent electrolytic action. Electricity discombines the components of the molecules of the electrolyte, and chemical activity combines them again. The action and reaction in the body of the electrolyte are equal and they are opposing actions.

Chemical action is always an action of combination. Even when it seems to separate the elements of compound molecules it does so merely because of the superior cohesive attraction of the elements in some new arrangement. It is always an attractive force, never a repulsive force, and can only make combinations. And the electric force is always a repulsive force and can only make dissociations.

There is in the cell, chemical combination on the zinc, and chemical combination and electrical dissociation in the electrolyte.

VOLTAIC ELECTRICITY

CHAPTER IV

THEORIES OF ELECTROLYSIS, AND ACTION AT THE ANODE

We have only as yet mentioned one theory of electrolysis, and what we have accepted in it is really only that part of the theory of Grotthuss which explains the mode of passage of the electricity between the electrodes; but besides the theory of Grotthuss there are several others, and it is only fair that we should consider them with a view to deciding whether any of them gives an explanation that agrees better with the facts of electrolysis than that we have so far used. It is a pity that our instruments are not fine enough to reveal the action going on in the space between the electrodes, and until they do so, we must accept some interpretation of the facts due to that action, and naturally we will choose that theory which best explains them to us.

Faraday, perceiving that the molecules of the electrolyte were employed in some way on this transfer work, supposed that they carried packs of electricity, and gave them the name of ions (travellers), which was a reasonable enough name, though they would have been thought to be very slow travellers, even in those days of stage coaches, if their rate had then been known. Since then we have learnt that electricity travels with extreme rapidity, and that the actual movement of the molecules is somewhat slower than the pace of a snail, so any such pack-carriage idea is impossible as the transfer is made instantaneously over great distances.

Grotthuss supposed that the constituents of the compound molecules were severally electropositive and

electronegative. That in water, for instance, the hydrogen is positive and the oxygen negative, and that they are attracted by the electrodes: and that when a current of electricity passes, that they change partners all along the line, and the liberated hydrogen and oxygen molecules at each end give up their charges to the electrodes. Here again we have impossible pack-carriage. If a momentary current is sent through the cell, it is instantly and entirely carried across and there is no electricity remaining in the electrolyte as would be the case if the action were as above.

Clausius tried to improve upon Grotthuss' theory by adding the separation of elements in solution. His theory is, that when a salt is dissolved it breaks up into its constituents, which wander free till by chance they find other temporary partners: the electromotive force of the current is supposed to control the direction of these chance wanderings, urging one set of wanderers one way, and the other set the other way, and so shepherding them to the two electrodes if lucky enough to have prevented an escapade on the way. This theory supposes, for instance, that a solution of common salt—sodium chloride and water—contains wandering elementary molecules of sodium and chlorine. But this condition is not possible, as there is no sign of colour from free chlorine, nor of combination of sodium with the oxygen of the water which is a very violent action. And besides if these molecules of the salt had the power given them to burst the bonds of cohesion which are weakened in proportion to the square of the distance of the particles asunder, what earthly force could bring them together again? And in what conceivable way does this help the current?

Since Clausius published his theory, enthusiasts have added to it and now the conductivity of the electrolyte is supposed to be in "proportion to the number of free ions multiplied by their velocity." That in an extremely dilute

solution all the ions are free, and by strengthening the solution, although it increases the number of ions, it does not increase the number that are free, and the conductivity of the solution is not therefore proportionate to the strength. Also the velocity of the ions is supposed to depend on the frictional resistance, or viscosity of the electrolyte: and their number depends upon the solvent, water having more than benzene or alcohol.

If one starts to explain a myth, it is easy enough to find reasonable explanations for all its fancies, and to string them in support of one another. Ovid could give us some instances of this sort. There is no possible use for free ions, and any snail-like velocity they could have would be of no help to electricity. The conductivity of an electrolyte probably increases with its strength, but not the action at the anode, because the interaction between the oxygen and zinc must be limited by the amount of zinc surface. Anything added to thicken the electrolyte, such as gum, sand, sawdust, should, one would suppose, certainly obstruct the action: and alcoholic and other solvents would resist the electromotive force more than water, because these fluids are more resistant to chemical change, and not because they have solutes in them. Pure water can be used as an electrolyte, but do its ions wander about free ?

One modern theory is that a compound molecule is composed of two parts: one of these, the metal kathion, has a positive charge of electricity bound in it, and tries to get to the copper: and the other, the acid radical or anion, has a negative charge and makes for the zinc. All of them together, whether anions or kathions, carry equal charges, and when they give them up at the electrodes they receive an opposite charge. This is a plentifully complicated reincarnation of Faraday's idea. Here we have molecules whose preference for a particular charge is so great that they hold it regardless of the opposite charges held by their

partners, giving up these charges they love, to take on charges they do not want, and receiving these obnoxious charges from a body that must have a store of both sorts mixed together. It is too complicated altogether and is merely another specimen of pack-carriage.

The pack-carriage theory dies hard. It is so simple, so evident, so undemanding of thought. Each ion takes up its load and darts across with the speed of light and the thing is done. Each molecule holds some of both electricities and pours them out, either, or neither, or both together as occasion demands.

The discovery of the slow movement of ions has upset the package idea, though obstinate enthusiasts still insist upon carriage by ions and corpuscular charges and measure the velocity of matter in exhausted tubes by the effect of the rays it produces. Hydrogen is said to be the fastest of the ions. With "one volt per centimetre force" to drive it, it takes an hour to travel four inches, under the best of circumstances: and this is "ten times as fast" as most ions move. The electric current travels with a velocity comparable to the speed of light, and if any component of an electrolyte were to travel with but a small part of that speed, the fluid would disappear in a moment in a flash of ardent heat.

Sir Oliver Lodge says that "the energy of one milligramme rushing along with the speed of light, is not less than fifteen million foot tons." Which is conclusive proof that none of the material driven by electricity, or in any other way, goes any way near the speed of light, for no vessel could hold it.

The latest theory is the electron theory, or rather two theories. One of these supposes these electrons to be "small aggregates of electricity" that thread their way between the ions: and the other, that the electron forms part of the ion and is shot out of it. They are both

variations of the pack system with the definitely added declaration that the electricities are material.

The swiftest motion of material is a snail's pace compared with that of electricity, so electricity can be nothing but motion: and there can be no aggregation of anything that is not material. Every modern theorist is convinced that electricity is motion, and yet they cannot get themselves to abandon the favourite old idea that it is part of matter like the raisins in a pudding. Electricity is a motion that can act on matter, and matter has no motion till motion is given to it. There is no electricity, no heat, no light, no sound, no motion of any sort in a molecule until a motion is transferred to it; as Soddy says, "there are no permanent resident forces in matter," and its sole inherent quality is inertia or opposition.

If the electricities were substances residing in the molecules, their loss would cause loss of weight, and also the completion of the circuit by joining the wires would not be necessary. The oxygen will corrode the zinc whether the wires are joined or not, and if any material electricity could be poured upon, or shot at the zinc, by the oxygen, it should be found there whether there were an outside arrangement of wires or an absence of such mechanism. But the junction of the wires is necessary, and it is so because the electricity is not a substance but a motion that requires a circuit to travel on.

Electricity, whatever particular motion it may be, is evidently a motion produced by the chemical action on the zinc: it is due to the combination of oxygen with the zinc, or other material of the anode: and there is none of the motion of electricity anywhere in the electrolyte, or in the wires of the circuit, till this chemical combination sends it forth. The oxygen is drawn, by the cohesive powers of zinc and oxygen, away from the cohesion of oxygen and hydrogen, to join the zinc and leave the hydrogen: and this

act of junction produces a motion: and this motion passes through the electrolyte reproducing in every molecule the action that produced it, causing every molecule of oxygen to separate from its hydrogen and to combine with the hydrogen of the molecule nearer the zinc: and the last of the hydrogen molecules at the copper is set free. A voltaic cell can be made of zinc, copper, and pure water, and the above is a description of the uncomplicated action in such a cell.

It has been said that "electric decomposition is the preponderance of one set of chemical affinities over another set less powerful: so chemical affinity and electricity are the same." But this is quite wrong. What difference of chemical affinity is there between two molecules of water? Electricity is an impulse that tends to separation, and chemical affinity is a cohesive force: by acting together they produce electrolysis, but they are different forces. It is much more correct to say that "in every case of chemical change there is a coincident electrical change, an electric flux—every case of electrical change is accompanied by chemical change: the force of chemical affinity is in some way disturbed by a momentary displacement of the molecules when a current passes through a conductor."

"Difference of potential produces electromotive force, which produces a current as soon as a circuit is completed." The chemical cohesion on the zinc sends out an impulse that decomposes the electrolyte, and this decomposition, in its turn, necessitates fresh chemical composition. The two impulses—electrical and chemical—are not quite equal, the electrical being the stronger, and they represent the swell and hollow of the wave of current, and the action goes on in every molecule used by the current. The material and the movement are, the one a thing moved, and the other forces that move the thing, and we must see that we do not get them mixed. The entire electric current is

made up of the thing moved, and the two forces, electrical and chemical, that move it.

* * * * *

To produce any particular sort of energy a greater amount of energy must generally be expended: and in every case the prime mover is gravitation under one or other of its several names, and the origin of this force we do not know,[1] but it is a force that seems to be constantly renewed. "Electrical attraction ceases on contact, but this cessation of attraction does not seem to occur among atoms."

The Falls of Niagara have plainly a great force of gravitation, and some part of the falling water is used to work machinery to produce electricity, and yet but a small part of the force so used is found available when the current is turned to domestic use. In other places steam-engines are used to work the electric generators, and here again there is a great loss of power, for only an eleventh of the cohesive power developed by the carbon and oxygen in uniting to form carbonic gases is found available at the last, the rest, more than ninety per cent., is lost for working purposes. Of course this lost energy is not dissipated at this enormous rate, but is used to heat the engine, elevate the smoke, and so forth, but so far as the resulting electricity is concerned it is a dead loss. The waste of energy in the voltaic cell does not seem to have been measured, but it is certainly very much less in proportion to electric outturn than with any other method, and this mode of producing current would be the best we know of, if zinc were as cheap as coal: its price being what it is, it is a most expensive method and so is unsuited for commercial use.

"No pile or battery can generate a sensible current, except by a sensible consumption of its materials in the shape of chemical action," and "every disturbance of electric

[1] Since discovered by the author.

equilibrium is inseparably connected with an equivalent disturbance of the molecules of matter," and "the intensity of the current is in proportion to the intensity of the chemical affinity of the zinc for the oxygen."

The zinc must be consumed or we get no current. Noad says that the electrodes have no attracting power, though acid inclines to the one, and bases to the other. The hydrogen that accumulates on the kathode does not cohere to it but leaves it quite free and unchanged." Other authorities, on the contrary, say that the action is entirely due to attraction. Perhaps Noad meant to say, that there is no increase of attraction of cohesion and attraction of chemical affinity due to electricity, for all bodies have the first and many the second attraction: and without the action of both these forces at the anode there is no current. But most persons would say that the chemical attraction is increased by the current in the cell: certainly the action is immediately increased by closing the circuit. The current must circulate many million times in a second, and with each circuit pushes some oxygen molecules against the zinc, which without this stimulus would not have moved. So though strictly speaking the force of chemical attraction has not increased, the amount of chemical action has. "It is the union of the zinc with the oxygen of the water, that determines the current in a common voltaic battery: and the quantity of electricity is dependent on the quantity of zinc oxidized." This is certainly true, and we have now to go into the details of the operation.

A solid molecule of zinc combines with a liquid molecule of oxygen to make a solid molecule of oxide of zinc. Before they join the zinc molecule is a small crystalline solid of some compact form, and the oxygen molecule is a liquid sphere. They come together and form a solid crystalline molecule, and they do this with contraction and, perhaps, the discharge of heat: the oxygen molecule becomes smaller

as solid than it was as liquid, and the zinc and oxygen contract in joining owing to the cohesive force of their mutual embrace: so there should be heat because of the double contraction. Yet as this solid oxide of zinc molecule is immediately changed by solution to liquid and therefore expanded after joining the acid molecule, there is no heat to be found in the cell because the expansion absorbs as much heat as was discharged by the contraction.

Now, in coming together, the zinc and oxygen molecules approach each other with constantly increasing velocity till they actually strike, not as solid and liquid, but as two solids, producing as they do so a concussion, which sets up a motion—a vibration—and this vibration is the electromotive force, and it is a vibration of æther, for no other material could convey it so fast, and the æther set in motion is that of the materials of the cell.

Let us carefully consider the conclusion that we have now arrived at. It is not one due to any theory invented for the occasion: nor to any mathematical equation bolstered with changeable constants to produce a suitable answer: but depends entirely on well-known facts, and these facts are in detail as follows.

In a solid compound of which one component is a gas, the gas is solid.

In chemical combination the different molecules attract one another.

In attraction the force increases with decrease of distance in proportion to the inverse square of the distance.

In chemical combination some form of æther disturbance is always evident: either actinic, light, heat, or—electric: and the disturbance is produced by the impact of the molecules that are combining.

In the case we are considering, the æther disturbance is produced in the apparatus we are using, and therefore in the æther in the apparatus.

No material, solid, liquid, or gaseous, can move with a velocity at all comparable with an æther vibration.

Based on these facts, which are plain enough, it appears that the electric current in the cell is a form of æther wave emanating from the combination of the zinc and oxygen, for it is unlikely that the union of the liquid acid and oxide molecules should produce concussion, and as the current can be produced in plain water without any acid, we may conclude that only the alliance of the zinc and oxygen is acting to produce the vibration. And here we find confirmation that force must be expended to produce force. The mutual energy of gravitation, or, as it is called in this case, chemical affinity, between the zinc and oxygen, produces an impulse which we call the electromotive force, which force, as it passes through any liquid, produces in it a change equivalent to the change that produced itself: it produces one equivalent of chemical change—no more, no less—whatever the fluid may be composed of. In an inch of water between the zinc and copper, the molecules are arranged in lines of a hundred millions in a line: the combination of one molecule of oxygen from the water with one molecule of the zinc produces a vibration of associated æther that separates the oxygen and hydrogen in every molecule of the water in a line of a hundred millions, and the vibration having travelled to the end of the line there liberates one molecule of hydrogen from the water—no more, no less.

In this, as in all cases of transmission of energy, a part of the electric force must be used up in its passage; but we must not suppose that when a current finds the distance to be travelled too long for its powers, that it gives up in consequence of the æther wave being reduced in amplitude and at last failing to do more work after going a certain distance. The force puts a strain on the conducting material throughout the whole distance at once, and if it is strong enough to complete the separation of all the mole-

cules in that line, the current passes, and not otherwise. This is shown to be the case by the effect of a storm cloud on the earth: the negative on the earth is drawn under the cloud and there is a strain established in the air between it and the cloud before there is any possibility of the passage of the current: when the distance is so reduced that the force can overcome the resistance to electrolysis of the air through the whole distance, the flash falls, and not before.

We have in this chapter discovered that the source of electricity in the voltaic cell is chemical combination: what we have now to find out is, what produces electricity in other forms of apparatus and in nature. If you will look back you will agree that none but simple well-known facts have been used in our examination. There has been no invocation of any of these extraordinary and mysterious agencies so dear to modern science: "which show more ingenuity than intellect in creation": "whose multitude shows their futility": and which containing imaginary mechanisms inconsistent with the laws of motion are only comparable to ancient vain attempts to manufacture perpetual motion machines—and on account of this very simplicity on our part, you must be prepared to see your conclusions ignored, or condemned and smothered in nebulous inanity: but hold fast; truth will conquer in the end, and perhaps before we finish our work we may have converts to our new credo.

VOLTAIC ELECTRICITY

CHAPTER V

THE CURRENT AND ITS EFFECTS

THE motion of electricity acts like any other motion. You strike a ball: it rolls along and hits another ball: the first stops and the other rolls away. The vibrations of radiant heat act upon a body: which in turn sends out reproduced vibrations to act on another body. The zinc draws the oxygen molecule towards it: they join and send out a movement to act upon another oxygen molecule and cause it to separate from its hydrogen and move in the same direction. And this movement is the product of two distinct forces, electrical impulse, and the chemical cohesion that caused it: and this causes the separation and recombination of the molecules of the electrolyte. In fact this vibration produces the same series of actions as those by which itself was produced. In all wave actions this is the case. The expanded molecules of the sun contract and produce radiant vibrations: these expand the molecules of earth's substances which in their turn contract and reproduce vibrations to act on other molecules, and so on continually. The separate zinc and oxygen molecules come together and produce vibrations: these separate other molecules which come together and reproduce vibrations.

So far as we can discover, then, electricity in the cell is an æther wave originating in the conjunction of solid molecules. And apparently there are two movements in the wave. First a movement caused by the chemical attraction, and second the movement that this originates to send the basic molecule to the kathode. And this duplex electric wave

formed by chemical combination and electromotive separation is the current, and it passes with great speed through electrolytes and on conductors. However we agreed when we began that we would put off our final decision till we had gone through every phase of the subject, so we will leave it for the present, and go on with our examination of voltaic action, only bearing in mind particularly to notice whether we come across, in any future study, any action that does not fit in with this deduction.

* * * * *

Let us now consider the arrangement of cells in a battery.

As may naturally be inferred, two cells, or more, produce more effect than one: but it has been found that the sort of effect that they produce depends on the way in which we arrange them.

If we join the positive (copper) wire of one cell to the negative (zinc) wire of the next, and so on in rotation, the cells are said to be in series, and the electromotive force is multiplied according to the number of cells, but the quantity of current is but little more than can be produced by a single cell. The force from each cell passes through and reinforces every other cell, but the amount of current is restrained by the size of the plates in the cells. It is like water in a pipe when the pressure is increased: the gauge of the pipe prevents the jet from becoming any thicker, but it comes with greater force. The electromotive force generated in a cell by the composition of its oxygen and zinc can only decompose an equivalent amount of water in that or any other cell, and the quantity of electricity is not therefore much increased by addition of cells in series, but its intensity, that is the amplitude of its waves, is increased: the action of cohesion is somewhat assisted but the strength of its produced vibrations greatly increased. Poggendorf came near this solution in 1840.

If we join all the copper wires together, and all the zinc

wires together, the battery is in parallel, and it gives more current, but the electromotive force is only equal to that of one cell. The rate of production of the force in each cell is the same as when acting separately. It is like the discharge of a number of water pipes of equal gauge and under equal pressure into a common conduit: the quantity of water depends on the number of pipes, but the velocity is no greater from the increased number.

"The strength or intensity of the current depends on the resistance and the electromotive force of the cells." The electromotive force in the cells is the impulse produced by the concussion of the zinc and oxygen molecules: it may be feeble or strong according to circumstances, but always produces the same length and velocity of wave: the only difference in the produced waves is in their amplitude: a feeble electromotive force can only produce a shallow wave, and can push its effect, that is the current, but a short way: the stronger the force, the deeper the wave: the less the resistance, the further any wave goes. When the molecules of the conveying material are strongly combined together, the electromotive force must be stronger to separate them, or no current passes. But this resistance of conductors we will consider in another chapter.

The current is the dissociation and recombination of the molecules resulting from the impulse of the chemical action at the anode: it is a wave movement acting on the molecules of the electrolyte: the impulse passes very swiftly and the movement of the molecules is instantaneous with it, but their progressive movement is very slow. The action is like that of the great tidal waves which move across the ocean at near a thousand miles an hour and scarcely displace the position of any of the drops of water.

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The voltaic current, as compared with electricity otherwise engendered, is a broad and shallow stream which

requires an ample conductor, or it will be interrupted and then many of its impulses will produce heat vibrations. "It has a great heating effect owing to its quantity, but it has little violence of electric shock and sparks are difficult to obtain." Or, as Noad says, "The intensity of voltaic electricity as compared with statical is extremely low, but the quantity extremely high." The electricity produced by a statical machine depends on the action of materials very much excited by friction, with a resulting intense, but slender current. The voltaic electricity depends on the gentle chemical activity of the anode, with the result of a mild current, and "the quantity of electricity in a voltaic battery depends on the size of the plates, the intensity on the number of cells."

This naturally makes a great difference in the physiological effects of this current as compared with that which comes from statical electricity. That gives one a racking shock, with painful contraction of the muscles. This gives a disagreeable aching at the joints and sometimes an itching of the skin, but no muscular distortion or agonizing spasms of pain, except, by the way, that "if the slightest excoriation or cut happens to be in the path of the current, the pain is severe." The writer from whom the above extract is taken does not explain why: but we know that it is because the electricity acts electrolytically on the moisture at the place and bathes one side of the cut with fresh acid and the other with fresh alkali, neither of which can be pleasant to exposed nerves.

According to Berzelius, "the taste of the positive current directed on the tongue is acid, and that of the negative current caustic and alkaline." If you will put a piece of zinc under your tongue, and a half-crown above it, and let the edges of the metals join in front of the tongue, you will feel a curious tingling sensation, and have a taste like potash: if you put the silver below and the zinc above the

sensation is the same, but the taste is acid. We have here a small voltaic battery in which the saliva acts on the zinc, and with the blood and nerves forms the electrolyte between the metals.

All the senses, seeing, hearing, smelling, besides tasting and feeling as we saw above, can be excited by similar arrangements. This action on nerve was in its day a great discovery and led to the construction of the voltaic pile, but such experiments are to-day merely tricks for the curious and tell us no more than that the blood and other fluids of the body are made up of substances that are decomposable by electric currents.

The body is not a good conductor and the resistance it gives to the voltaic current prevents all but a small part from passing, and for the same reason the current passes through or over every part of the body that is any way near the line between the conductors. Statical electricity might send even less current through, but it would send it in one nearly straight line, and with great force overcoming all resistance: hence its destructive effect.

"In the human body the blood is the best conductor, then the nerve substance." The blood is coagulated by strong currents, so it is not advisable for funny persons to play tricks with electricity: a certain amount of current means death, so let no one treat a friend to a shock till he has tried it on himself: the friend might be a sensible person and a loss to society. "Electricity in the first place acts upon the nerves causing spasms, secondly it destroys the tissue either by burning or electrolysis, the blood becoming coagulated. To restore a person who has been rendered insensible by electric shock, all the same restoratives should be used as for a person drowned. Electric currents should not be used at all except with great care and under the direction of a regularly trained surgeon. In the few cases where some fancied good has accrued (from advertised

magnetic and galvanic appliances) the curative agent is probably not magnetism but flannel." This is from Silvanus Thompson's lessons in electricity and magnetism, and is very good advice.

Without going into particulars of experiments with legs of unfortunate frogs, or horrible descriptions of the effects of electricity on dead criminals, there are one or two points worth considering with respect to the action of the current on the animal system. Some scientists say that our entire nervous system is worked by electricity: that the nerves are a mere set of voltaic batteries and that their action is simply due to a creation of difference of potential between the two ends of the nerve: that if you heat one end, presto, the current carries the news to the other end and the appropriate muscles respond. But this theory is founded on vague generalities and not confirmed by experiment.

There are two points to be borne in mind. One is that there must be a complete circuit for a current to traverse: and the other is that the voltaic current must travel along a nerve to produce contractions in a muscle, for it has been found that muscle by itself is a nonconductor and is not acted on by this sort of electricity.

It seems rather against the idea that the nerves work by their own electricity, that contraction of muscular fibre cannot be effected by electricity directly applied to muscle, but is easily set up when the nerves are used as *conductors* and the current sent to the muscle through them. And the following also is against the idea—namely, that though the nerves are constantly in connection with muscle, they are not constantly acting, which they should do if they formed a circuit and were electricity producers.

Another strange thing is, that other substances containing contractile filaments, such as protoplasm and plants with sensitive leaves, both of which have these filaments, are contracted by a current through their substance though

in them no nerves have been found. It certainly seems as though the electrochemical changes produced by the current in those substances irritate the filaments and so make them contract: and if so, we should think that a similar cause occasions the contraction of muscle: that in fact the nerves set up chemical change in the substance outside the filaments of the muscle and thus cause their contraction by the action of the changed substance on the muscle. It is quite certain that no filament is lost through exercise, and if not, then the loss must be in the interfilamentous substance, and on this supposition we can understand fatigue coming on when all the change possible in this substance has been done by the nerve action and there is no more left to be changed to do work on the filaments. The worn-out stuff that is left is not poison, as some say, except that it occupies the place of fresh unchanged material and must be carried off to make way for it, and now is the time that stimulants to the circulation are useful to induce nature's commissariat to hurry up a fresh supply of what is needed, and which by its action will give, what is called by runners, second wind.

The muscle is only contracted by electricity when the current through the nerve is made or broken: a continuous current has no effect. The direct current, that is the current that is in the direction of the ordinary nerve current away from the brain, affects the motor nerves most on making the circuit, and the sensory nerves most on breaking it: and *vice versa* with an oppositely directed current. The sensation felt by the sensitive parts of the body is greater towards that part that is nearer to the negative side of the battery. If the current travels along the motor nerve away from the brain, that is with the negative wire on the muscle and the positive on the nerve, there is strong contraction: with the positions of the wires reversed the contraction is feeble.

It would appear from all this that when a voltaic current

is sent through nerve and muscle, action in the nerve depends on a change in the position of its component molecules: that the change is in one direction only: and that the current takes oxygen from the muscle. But in ordinary nerve action though the two first probably occur, the oxygen does not leave the muscle, but is consumed in it, and in its new combination is carried away by the blood, and there is apparently no electrolysis: and also in nerve action there is no sign of return current. We should judge from this, that ordinary nerve action is not electrical: for though similar results are produced by natural nerve action and electricity, they are produced dissimilarly.

VOLTAIC ELECTRICITY

CHAPTER VI

THE VOLTAIC PILE AND ELECTRODEPOSITION

THE first contrivance in the way of a battery was the voltaic pile. It is a thing now quite gone out of use and not seen except as a curiosity, but it exemplifies the principle of the cell so clearly that it is well worth examining. We have seen, or say tasted, how a piece of zinc and a piece of silver with a damp tongue between them produced a current. It is not necessary to use the tongue as the intermediary, for any substance, that being porous can be made damp throughout, does quite as well. So if we put a piece of blotting paper wetted with salt water on a piece of zinc, and a piece of silver on the paper, and join the metals with a loop of wire, we have a voltaic cell perfect in the essentials but not very strong. Volta's first instrument was a pile of plates about four inches square of silver and zinc with moist flannel above, placed in series one over the other and ending with a zinc plate. In constructing these things thickness does not signify: moistened paper with gold leaf on one side and zinc foil on the other acts as well and strongly as thick plates would do. In fact thinness is an advantage, as the thinner the plates the more compact the arrangement and the less the cost.

In the Clarendon laboratory at Oxford, there is a dry pile made sixty odd years ago, and the terminals of it are attached to two small bells, between which is hung a brass ball to swing between them and ring them alternately, and it is no doubt doing so still. Zamboni devised a pile in which several thousand round bits of paper, with zinc foil on one

side and binoxide of manganese on the other, are placed on one another in a glass tube: the resistance is very great as the paper gets its moisture from the air, but the enormous number of cells—for each zinc, paper, manganese, forms a cell—gives it great electromotive force, so that it will give small sparks.

Volta considered that the action of his pile was due to the contact of the metals, hence his arrangement of two metals at the ends. In the cell, as we have seen, the wire from the copper is positive and that from the zinc negative, while in Volta's pile the terminal zinc is positive and the terminal silver negative: this seems an upsetting of rules: but there is no such inversion, because the end pieces are not parts of the battery, but merely conductors like the wires of the common cell, and the plates that are really the terminal electrodes are the zinc below and the silver above and which are inside the terminal plates.

Volta in pursuit of his theory examined many metals and arranged them in a list according to their apparent interactions: but in fact the differences that he ascribed to mutual electrical potential were due to chemical potential: sodium the easiest to oxidize being at one end of the series, and graphite the most resistant at the other. As no two metals are alike in this chemical reaction, any two brought together with moisture between them will show electric action, and they will do this in air when they seemingly have no intervening moisture, which may have led Volta to form his opinion, but they act because of the electrolytic action of the layer of condensed air between them, and it is not on account of their contact that they can act, for there is no such "result if they are brought together in vacuo, in dry hydrogen, or nitrogen." And this very action is a source of weakness in the pile as it tends to produce a reverse current—polarization in fact. If any two metals are cleaned, and heated to drive off condensed gas or vapour,

and are then placed in contact in any simple gas, there is no action: and if they are so prepared and placed in air, there is for a time no action until they have recondensed on them a fresh film of liquid air.

In investigations connected with heat there is an instrument used—a heat detector—called the thermopile, which is made of small rods of bismuth and antimony placed in a bundle with their alternate ends soldered together: a very slight change of temperature, such for instance as would be made by moving to stand in front of the instrument at six feet away from it, will send a current of electricity through it: but though the metals have great potential differences and their ends constantly touch, there is never a sign that any action takes place on that account. So we may reject the contact theory and stick to the chemical, which is, that one metal has more potential than another because it is more easily acted on chemically.

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The examination of the action of electricity in electro-deposition will not give us much increase of information, but the processes are of some interest and we may as well glance at them to make sure that there is nothing in them contradictory to our deduction that electricity is a wave in the electrolyte.

There are three definite processes, which are all of commercial value and require care in application, with knowledge of appropriate solutions and of the strength of the currents to be employed—electroplating, electrotyping, and electrorefining. In all of them the principle of the process is the same: a plate of the metal to be deposited is connected to the copper wire of the battery, and is immersed, as the anode, in a bath of solution of some salt of the metal: and in the same bath, as kathode, the objects to receive the deposit are placed and connected by wire with

the zinc of the battery. The current acts on the salt molecules, separating their metal and acid components, and deposits the metal molecules on the objects put to receive them, and drives the acid to the metal plate which is consumed away by it as fast as the deposit is made.

In electroplating what is desired is a thin and hard covering and the operation is therefore slowly conducted. Gold, silver, copper, and nickel are the metals employed to coat some baser metal, and of these, for merely experimental purposes of observation, copper is to be preferred, as it is at once the easiest to work with and the cheapest.

Eight ounces of copper sulphate, two and a half ounces of sulphuric acid, and a quart of water make a good bath: and one cell is sufficient for the working. The object on which the deposit is to be made must be cleaned thoroughly, for the touch of a finger or the least tarnish will spoil the coat. The thing should be washed in hot potash solution and, if tarnished, passed through solution of potassium cyanide: then rinsed and hung in the bath.

Only brass and the less oxidizable metals can be coated in this way. For iron, tin, and zinc a first coating must be given in an alkaline solution. This is made by dissolving four ounces of copper sulphate in a pint of water and adding strong liquid ammonia till the sediment first thrown down is dissolved: the liquid is then of a lovely dark blue: then add solution of potassium cyanide until the colour has gone, and then add as much more of this solution of cyanide as amounts to about a quarter of what has been used: add water to make the whole equal to a quart. Warm this to 140° F. —not more—and use two cells in series to work it. As soon as the articles are well covered, take them out, wash them in water, and finish the plating in the other bath. In the alkaline (ammonia) bath, there is a double displacement of molecules which is so easily effected by the current that

the iron or other metal is preserved from corrosion, which would certainly happen were it put unprotected in the acid bath.

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In electrotyping the object to be attained is the copy of some medal, wood-block, or sheet of set up printing type, and in every case the process is the same. Clean the face of the article to be copied with potash water or benzine, taking care to remove any ink or dirt that would interfere with the sharpness of an impression (but not troubling to remove tarnish or bronzing), and black lead it. Melt some beeswax with sixteen per cent. of Venice turpentine and three of plumbago: and keep this as hot as boiling water for a quarter of an hour so that no water may remain in it, for the least moisture would be sure to cause it to crack: then spread it in a sheet larger than the article every way: when cold press a copper wire into the edge all round and twist the two ends together that they may be joined presently to the copper wire of the battery: then blacklead the upper surface of the wax and the wires: press the article on the wax till it has given a perfect mould—this will require a hydraulic press for large sheets. Now remove the article and pass a hot iron over the back of the wax and over such places round the edge as are not to be deposited on, and again blacklead the face, and when dry pour a stream of water over it to remove superfluous blacklead and hang it in the bath.

The bath should be as strong as possible to begin with and the current high, and the solution should be gently stirred with a feather: afterwards the current should be less. This insures a uniform first deposit followed by a hard one. When thick enough (a hundredth to a thirtieth of an inch) remove the wire, pour warm water on the copper and the wax will come away: any that does happen to stick wash off with boiling potash water: dry and lay face down-

wards, and cover the back with tin-lead foil sprinkled with sal ammoniac, and heat the foil till it is melted: then pour in the backing metal made of lead with five per cent. each of antimony and tin added: and when cool trim as required. For small objects the mould may be made of plaster of Paris or of sulphur, but for large things these cannot be used as they shrink too much: hot guttapercha may also be used. In whatever way it may be done it is a troublesome business, but very beautiful copies may be made in this way of very precious articles, which also may be considerably damaged in the process. *Verb. sap.*

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In electrorefining the object is to get the pure metal as quickly as possible. A plate of the common commercial metal is used as anode and is consumed, its impurities fall to the bottom of the bath, and the pure metal is deposited on a plate of the pure metal used as kathode. A strong current is used as it does not matter in what state the deposit is made, whether spongy or hard.

For every sort of electrodepositing done on a large scale, electricity is now supplied by steam motors which are much cheaper than zinc batteries.

Copper as it is extracted from the ore is pure enough for general use, but for a particular purpose, when a high standard of purity is needed, the metal is usually got electrolytically, when the arsenic and other impurities are left in the solution.

* * * * *

The action in liquid is what is most often seen and studied and it is supposed by some to be the sole method of electrolysis, but it may sometimes be forced on compound solids which are conductors, and it decomposes them by means of their water of crystallization in the same way as it does the liquid electrolytes. Sir Humphry Davy discovered

potassium and other metals by this method. By placing solid potash as the electrolyte, between a plate of platinum as kathode, and a copper wire as anode, and sending a current through the arrangement, the metal was disengaged in little globules on the platinum, while the oxygen acted on the copper.

It is electrolytic action also that causes the separation of minerals in furnaces worked by heat and electricity combined. Aluminium is extracted in this way. The oxide—that is clay—is put in a brick furnace lined with carbon, and between two bars of carbon through which a strong current of electricity is sent: the heat is intense: the clay gives up its oxygen to the carbon to be changed to gases, and the aluminium separates pure. There are other electrical methods of reducing aluminium and other metals, but all are as evidently electrolytic and chemical as the above-described method.

STATIC ELECTRICITY

CHAPTER VII

THE ELECTRICAL MACHINE

"WHEN two dissimilar substances are rubbed together they produce electricity." This was in a way known to the ancients, who however looked on it merely as a curiosity, and it was not till about 1650 that the first electrical machine was invented by Otto von Guericke, who used a globe of sulphur which was turned while pressed by bare hands, and with which he was able to produce sparks. This was more than a hundred years before Galvani had his first inklings of what we call voltaic or galvanic electricity. The sulphur was soon replaced by glass, and the form changed gradually till it became a flat wheel of glass—a disc of plate glass of uniform thickness. Use was made of rubbers instead of hands, and they also were improved till now they are leather or silk cushions stuffed with hair and covered with an amalgam of tin, zinc, and mercury, mixed with grease.

The plate pattern electrical machine is a circular piece of thick glass, pivoted at its centre, and placed upright between two wooden supports rising from a broad base. The pivot passes through the supports; and the cushions, which are on both sides of the glass, are fastened to the supports, a pair above and a pair below the pivot; and at one end of the pivot is the handle for turning the glass. On the opposite side of the glass to the handle is an arrangement of brass bars, or rather tubes, supported at the height of the pivot on glass pillars fixed in the base: the principal parts are two bars, parallel to each other, which are called the prime conductors, and they are placed so that one end of

each is close to one edge of the glass; and each of these ends has fastened to it a bar which is bent so as to pass round the edge of the glass and enclose it in a long **U**; and the inner sides of these bent bars have a number of sharp points directed towards the glass but not touching it. The other ends of the prime conductors which are furthest from the glass are joined by a cross bar.

There are several precautions which must be observed in using an electrical machine if we wish to produce anything but perspiration and vituperation by working it. There must be no dust on it. The insulating pillars, even if made of glass, are better for being varnished with a thin coat of shellac varnish. If the machine has been for long out of use, it should be cleaned and have a fresh coating of amalgam. The whole machine is better for being warmed to drive off any moisture that may have condensed on it. And when you have done all these things you may find that it will not work because the weather is damp. It is indeed a very uncertain machine and has been given up in favour of influence machines which are much more reliable. We, however, must not give it up until we have mastered what we can of its mode and effect of action, a clear understanding of which will profit us much in our study of static or frictional electricity.

The following is the action of the machine. The glass plate is turned by means of the handle and rubbing against the amalgam on the cushions, positive electricity is developed on the surface of the glass, and negative on the surface of the cushions, in exactly the same way as these electricities are developed when a glass rod is rubbed with a piece of silk. The glass rod and its silk rubber are in fact a feeble electrical machine, the glass carrying the positive and the silk the negative charge.

If the whole machine, plate, rubbers, and conductors, are well insulated, we can, by working the handle, create and

store up, as we may say, a certain amount of electricity in the machine, but however much we may labour there is a limit to this amount, and we can store up just so much and no more: but if we put the rubbers in connection with the earth, a very much stronger electrification is at once given out and continues to be produced as long as the plate is turned.

The electricities produced by the machine are the same as we had from the voltaic battery: the one, the positive, accumulates in the conductors, and the other, the negative, is stored in the insulated rubbers. When the rubbers are connected with the earth, a great quantity of electricity is stored in the conductors and gives strong sparks in escaping from them. And if both rubbers and conductors are connected with the earth, all the electricity we may produce passes away and our labour is wasted.

In some works on electricity it is very explicitly stated that the positive charge on the glass is carried by it till it is opposite the collecting combs of the prime conductor, and that then the points of the combs discharge on to the glass plate the negative electricity of the conductor, and so neutralize its coat of positive electricity, after which the plate goes on towards the rubbers free to accept a new charge: meantime the positive electricity of the prime conductor is repelled to the end furthest from the glass.

There seems to be something wanting in this explanation, and when it is added, as it sometimes is, that the current of positive electricity flows from the ground for the charging of the disc, it only adds to the incomprehensibility of the whole story.

No one can doubt that electricity is produced by the rubbing of the glass disc, for it is produced in considerable quantity even when the whole machine is insulated from the ground. Also it is certain that positive and negative electricities are produced as we can collect the one from the

conductor and the other from the rubbers. And also it is certain, that when the rubbers are connected with the ground, positive electricity can be continually drawn from the conductors, and the negative electricity continually flows into the ground, as any galvanoscope will show us.

No doubt at starting, the positive electricity of the prime conductor is driven to its furthest part, and the negative attracted towards the glass, but the whole of this negative electricity must be used up at the first turn of the machine, and no more can be got off the conductor to neutralize the positive charges produced by succeeding turns. And as to the wire carrying positive electricity from the earth, the disc does not want any from the earth, as it is making it for itself, and "positive and negative electricities are generated in equal quantities by friction," and the earth wire is merely a means of getting rid of the negative electricity which has been produced by the machine.

The old idea that the points of the collecting combs absorb the positive electricity from the glass plate seems more reasonable, for sharp points both collect and discharge electricity. It is certain that if you ornament the knob of your electroscope with a needle, it is completely discharged in a few seconds; but also, if you electrify a glass rod, and pass its length over the needle point at about half an inch from it, the rod will be more thoroughly discharged into the electroscope than it would be by contact at any one point with the needle. This experiment must be done slowly or the gold leaves will be broken.

As our inquiry is more particularly directed to the discovery of what electricity is, it does not perhaps very greatly signify to us in which of the two ways the conductor gains its electricity, but still one does not like to leave a point doubtful, and when one sees a brush discharge coming from a point fixed on the prime conductor, and notes the vehemence of it, and the time of its continuance, which is as long

as the machine is worked, it does not appear possible that all this discharge can come from the conductor alone and that none of it comes from the glass disc: on the contrary, one is convinced that the opinion of the majority is the right one, which is, that it is produced by the working of the machine and does certainly come from the glass, and must be collected by the combs.

We will agree then that the electricity is produced by the rubbing of the glass and rubbers, just as certainly as it is by the rubbing of the glass rod by the silk handkerchief. The amalgam rubbing the face of the glass produces positive and negative electricities which are separated, the one to be carried away by the glass and the other by the amalgam, and that on the glass is taken up by the collecting points and is driven on to the conductor with such violence that it breaks into long sparks and brushes to get free. It is plain from this, whatever else may happen, that some violent action is taking place where the rubbers touch the glass, and as "friction exerts a chemical influence, even silicious minerals such as mesotype, basalt, and feldspar, becoming partly decomposed and giving off a portion of their alkali in a free state," we will try to find out whether any sort of chemical action can occur.

Whatever action occurs, is plainly brought on by friction, and friction produces heat (they say) by the violent mechanical motion of the molecules causing vibration in the æther. This is a very easy explanation, but the production of both heat and electricity may be explained in another way, and that is, that the mechanical motion forces the surface molecules into chemical combination with the condensed oxygen on the surfaces, and that this combination produces the heat and electricity.

Considered thus, we see that the rubbers have taken the place of the zinc in the voltaic cell, and the glass that of the copper. The amalgam is acted on and to it the negative

current goes, the glass is not acted on and carries away the positive electricity. It is by the oxidation of the amalgam that the electricity is produced, and the oxygen is provided by the condensed gases of air on the surface of the glass. It is as much a chemical action as is the action in the voltaic cell. The amalgam is the oxidized anode, the condensed air the decomposed electrolyte, and the glass the kathode unacted on. The electromotive force of the voltaic cell depended on the weak unaided force of chemical affinity to produce it, and it was weak accordingly: in the machine, muscular force assists chemical affinity by driving the units violently together, and the consequence is a violent electromotive force. It is like the increased action produced by bellows on a fire, or by a rod in stirring a solution.

Still, though we may be convinced on these subjects, there are others who seem to think that the electricity is not produced by the friction of the rubber on the glass, but that it is, as it were, pumped out of the ground and merely divided into positive and negative by the machine: and these would say, in support of their theory, that the frictional electricity is not in proportion to the friction: for two pieces of the same material, smoothness, and temperature may be rubbed together to all eternity and yield no electricity. If friction produced electricity alone, this would be a serious objection: but, as everyone knows, heat is plentifully produced by such rubbing: and the more alike the objects rubbed together are, the more the heat and the less the electricity. We must also remember that any motion can only reproduce an equal amount of motion, and if it produces the motion heat it cannot produce that other motion electricity: and also that metals of similar potential are similarly acted on, and therefore if they produce any electricity it is mutually cancelled as fast as it is made.

When we bring these facts into consideration they show

that the want of proportion between friction and electricity gives us an additional argument in favour of the chemical theory rather than one against it, and confirms the idea that the action between the surfaces is electrolytic. And apparent exceptions are not difficult to answer, for if two good unlike conductors rubbed together give apparently little heat or electricity, it is because the heat flows through the material and is lost to us and the electricity flows away over the surface, and even if we take the trouble to insulate the objects it escapes at every point and angle. And if two unlike nonconductors rubbed together show ardent heat at the surfaces rubbed, it is because the heat cannot escape by conduction, and if they show little electricity it is because their material is not oxidized easily, and wanting chemical action electricity is also wanting. Certain unlike bodies rubbed together produce—as we see with our glass rod and silk—electricity, and in this case the silk has, after the rubbing, a peculiar smell: some part of the silk, or something associated with it, has been oxidized by the condensed gas on the rod: pass the rod through a clean frame to drive off the gas coating and no electricity is produced however much you may rub it.

The above makes it plain why one of the bodies in the machine is a conductor and the other a nonconductor, that the one must be oxidized and the other unchanged. Being very different in potential they produce more electricity than heat: the negative electricity is not wanted and flows over the conducting earth wire to the earth: the positive remains on the face of the nonconducting glass till it is picked up by the collecting combs. The further apart the two materials are in conductivity and the further apart they are in oxidability, the more the electricity and the less the heat produced. So proportion of friction to quantity of electricity has no bearing on the subject.

The reason for using a nonconductor as the material for

the plate of an electrical machine is that the electricity may not escape as it would do from a conductor, or spread itself all over the surface as it would do on an insulated conductor, in either of which cases all the action would be annulled.. The charge on the glass remains on the spot on which it was placed, and does not move from it till it is picked up by the collecting combs.

STATIC ELECTRICITY

CHAPTER VIII

THE CHEMICAL ACTION

The oxidation of the amalgam, or some other chemical action, is absolutely necessary to the production of electricity by friction. Wollaston found that the machine would give no electricity when worked in atmospheres of hydrogen, nitrogen, or carbonic acid. There is plenty of oxygen in carbonic acid, but its attachment to carbon is evidently greater than its affinity to amalgam, and, if you care to try the experiment, you will find that neither mercury, zinc, nor tin, shows any trace of oxidation if covered with carbonic acid gas. We might try experiments with other gases, to the damage of the machine probably, but we do not need them, sufficient has been done to give us enough evidence for what we want to prove. We see that the machine produces electricity when the amalgam is chemically acted on, and will produce none when the supply of chemically acting material is cut off, so we may conclude that chemical action is a necessary part of the process, and that it is no theory but a fact that is borne out by every experiment.

"In electrical machines the oxidation of the amalgam by the friction is essential: the development of electricity falls off when amalgams of difficultly oxidizable metals are used: and no electricity can be obtained from a machine worked in pure carbonic acid gas."

To produce the oxidation of the amalgam it is necessary also that there should be some action in the film of liquid air which is on the glass, and which is acting as electrolyte.

We cannot suppose that this is a chemical process, because the oxygen and nitrogen that make up our air are not compounded in any way but merely mixed, and this is no doubt their state whether they are gaseous or reduced to liquid. Still the molecules, touching one another, must have some attraction of cohesion towards each other, making them cling together, in the same way as we see that the molecules that form a drop of water must, with some force, cling together to be able to keep the form of a drop: indeed "molecular cohesion between neutral molecules at very minute distances may be very great, almost indistinguishable from chemical combination," and as the average liquid-air molecules are two and a half times heavier than the three molecules that form a compound molecule of water, they must cling together with one hundred and fifty per cent. more force than the water molecules do. It is on account of this greater cohesive force that we find so much difficulty in removing the film of condensed air from surfaces in comparison to the removal of a film of water, so we may conclude that the molecules of the liquid air cling together with such force as to give the electromotive force something to do—some body with opposition to react with and produce an electrolytic movement—some allied molecules to be separated so as to make new alliances.

The meeting of the molecules of oxygen and amalgam, forced together, produces strong vibrations of electromotive force, which travelling through the liquid air compel, with each throb, the oxygen molecules one step towards the amalgam, and the nitrogen one step towards the glass.

What happens when the nitrogen arrives at the glass? Is it given off into the common air? Nobody seems to know or to have given this item any thought, probably because the thought of such action occurring has not occurred to them, though it is plain that it must happen.

Then again what happens when the electromotive force reaches the glass? Nobody knows, but for certain it is not changed to heat, nor dispersed, nor annulled, for it remains active in some way on the surface of the glass for some time, and can be transferred to the conductors by the collecting combs.

Having arrived at this impasse let us retire and consider something else. Let us consider the other various methods in which this sort of electricity is generated.

"In forcing liquid through a porous substance a current is produced." We might say, if we were disbelievers in the necessity of chemical action for the production of electricity, that there is none of it here: the stuff comes out just the same stuff as it went in. "Forcing water through sulphur with a pressure of an atmosphere (15 lbs. to the square inch) produced a potential difference of over nine volts. When forced through porcelain, the difference was about a twenty-seventh part as much; and when through bladder only about one nine hundredth." The pressure would of course drive the water but slowly through the apparently solid impervious sulphur, faster through the porcelain, which we know is pervious to moisture when unglazed, and fastest of all through the bladder: and owing to the pressure being unchanged and the resistances and the velocities due to them different but equal in aggregate, the friction in all the cases would amount to the same. It is then something else than friction that occasions the great difference in electrical out-turn: and as it is not mechanical friction it must be molecular disturbance.

The porous passages of the sulphur are much smaller than those of the porcelain and bladder, and we must assign the greater action to the greater constriction of these passages. The oxygen and the hydrogen of the water molecules are severed and recombined as they are forced through these narrow ways, and this is all that is needed for the

production of a current. Recombination, as we have seen, is what produces electromotive force.

A jet of steam issuing from a boiler produces electricity by the friction, it is said, of the steam against the orifice. This action of steam was discovered by accident. An engine-man happened to put one hand on the lever of the safety-valve of his engine, while his other hand was in a jet of steam that came through a crack in the cement fastening the valve to the boiler, and he received a severe shock. Sir W. Armstrong followed up the investigation from this initiative, and for the purpose of his experiments had a boiler made, which, with its furnace, was supported on glass legs. With a pressure of a hundred pounds to the square inch, a plentiful supply of electricity was produced when the steam was allowed to escape from a jet.

"The body of the boiler gave negative, and the jet of steam positive electricity."

"After working for some time the conditions changed: the boiler became positive and the steam negative."

"Washing the boiler out with water made no change after this, but washing with potash and water restored the first state, and with a little potash in the water in the boiler the quantity of electricity was very much increased."

"By the addition of a little nitric acid, or of nitrate of copper, to the water in the boiler, the steam became negative and the boiler positive, and washing out the boiler with dilute nitric acid had the same effect."

"Oil of turpentine changes the electricity of the steam whatever it may be, and so also with olive oil."

"When the electricity of the steam is carried to the earth, the production of electricity is much increased and the discharge from the boiler much stronger: sparks fifteen inches long being produced."

"When the steam was negative through the addition of nitric acid to the water, the putting of a wooden tube inside

the copper jet changed the steam to positive and the boiler to negative."

"With moist compressed air substituted for steam, the jet of air was positive and the container negative, as with the steam and boiler."

"With dry air or dry steam no electricity was produced."

It is plain that the action is between the moisture and the metal jet, and it is easy to see the likeness of this steam electric machine to the ordinary frictional machine and to the voltaic cell. As it was first constructed and used, the copper jet was the anode, and represented the amalgam of the frictional machine and the zinc of the cell: the steam was the kathode and stood for the glass and the copper: and the water, condensed from the steam on the jet, was the electrolyte the same as in the cell and stood for the condensed air on the machine.

While the steam jet was positive, the boiler represented the earth in the electrical machine: when the jet turned negative it became the prime conductor.

The water molecules brought into violent contact with the metal of the copper jet combined with its surface molecules, and by this combination produced the waves of electromotive force which passed from the copper anode through the water electrolyte to the steam kathode. The oxygen of the water combines with the metal to oxidize it and the hydrogen goes free in the steam. It would be interesting to confirm this by practical experiment, but it would be an expensive business as these steam machines are not made now.

Water is a necessity as Faraday discovered, and neither dry air nor dry steam has any electrical effect though they produce heat in quantity by friction. "If the jets were allowed to become so hot that they condensed none of the steam as it passed through them, there was no electricity produced until they were cooled down again."

When the whole steam machine was insulated, the steam could only get rid of its electricity by means of the steam jet in a sort of brush discharge, and the boiler discharged its electricity by "sparks and coruscating trails," and no doubt much electricity was wasted and turned to heat working against the resistances. But when the steam was put in connection with the earth, by letting it blow against a collecting comb with earthed wire, and its electricity had found a free road of escape, the whole effect was greatly increased, and long dense sparks were given off from the conductor of the boiler. This reminds us of the similar conduct of the glass electrical machine before and after its rubbers were connected with the ground.

It is not at all necessary to insulate the boiler of these machines: connected with the ground, like the amalgam in the other machines, it would certainly act better: positive electricity in large quantity can be drawn from the escape steam of railway engines which are in no way insulated, and which act the part of anode: but it was found to be much more convenient to take the electricity from the boiler, and in order to do this it must be insulated.

The addition of potash to the water increases the effect, because the potash solution makes a better electrolyte than the pure water, giving up its oxygen to the copper more freely than the water does.

The action of the nitric acid was to reverse the action, probably because its vapour had more affinity to the steam than to the copper, and in this way changed the steam into anode.

Oils cannot be said, when hot, to have any chemical action on metals which they preserve from oxidation; and certainly they are not prone to alliance with water, but their vapours may have some interaction with steam, and if so would cause the steam jet to become the active terminal, that is, the anode. Faraday thought that the

change caused by the addition of oils was owing to the globules of water having a film of oil upon their surfaces, which coating received the friction and so prevented the water from having any. But this conveys no explanation to us who consider that friction is of no account in this matter except as an excitant to chemical action, and in this case the chemical action was not suppressed but changed.

After working for some time the action of the machine is reversed and the steam becomes negatively electrified. As the water boils away the impurities that it has in itself and that it has derived from the boiler would, perhaps by long heating, be dissociated into their component molecules, and the vapours of their acids would be carried up with the steam to act in the same way as the vapour of the nitric acid acts.

It was found that the form and substance of the jet had a considerable effect on the results. In the case of the wooden tube inserted in the copper jet, it is not difficult to find the reason for the increase of activity, for now the steam is no longer kathode but merely a conductor, and the working parts consist of copper anode, water electrolyte, and wood kathode: and the wood being so much more intimately in contact with the water than the steam was, is the cause of the improvement.

The steam electrical machine was found to be very powerful, but it was distractingly noisy, and covered everything near it with the moisture of condensed steam; but even if it had not had these disadvantages it would not be used now, as all electrical machines are shelved in favour of electromagnetic motors.

" In a volcanic eruption, electricity is generated by the friction of the steam against the walls of the vent; this produces the thunder storms that accompany eruptions. The steam condensing in the higher cold air falls as heavy rain." In volcanic eruptions Nature assumes a position

sufficiently strong to prevent even the most inquisitive from poking their noses into her business, and what happens in these cases will no doubt always be matter for conjecture, but so far as we are concerned we have gained sufficient knowledge to assume that there is always plenty of chemical action going on in the eruptions, and more than enough to provide for all the electrical phenomena that have been found to occur, and to produce mephitic vapours for the suffocation of hundreds of unfortunates as well. We can only theorize about these cases, but probably it is not the friction that directly produces the electricity, but the interaction of the chemical affinities of the substances ejected and forced into combination by friction that is produced by the eruptive force: and the electrical force so produced is probably much of it dissipated in the earth: and the thunder storms are probably produced by the electrified dust which is carried up with the steam.

Apparently friction has just the same effect as the stirring up together of chemically interactive substances would have: it brings the different molecules more quickly together and so hastens their chemical union. And the cause and course of production of the electric force in statical electricity is evidently the same in every respect as in voltaic electricity. It is a joint action of chemical combination with electrolytic conduction. The electricity is due to the action of the machine, and has nothing to do with external influences, and the action of the machine is due to oxidation of the amalgam. Do not let us forget this, and also that the production of the electricity is made possible by the use of particular substances and by the particular arrangement of the machines.

THERMO ELECTRICITY

CHAPTER IX

ACTION OF HEAT AND CURRENT ON JUNCTIONS

THERMOELECTRICITY is the most difficult part of our subject: difficult to understand and very difficult to explain clearly: we must therefore attack it carefully and with patience.

If two metals form a circuit and one of their junctions is heated, an electric current is set up. This was discovered by Sebeck in 1821, and great hopes were raised of the application of it to some useful purpose, but the amount of electromotive force produced is so very small that no economical use can be made of it.

There is, however, a small instrument made on this principle, named the thermopile, which is very useful to heat investigators when observing very small changes of temperature. It is made of small bars of bismuth and antimony joined at their ends but separated everywhere else by some nonconducting substance: they are packed in a cubical case which is open at opposite sides where the joined ends are exposed. The bars are so arranged that, if they were stretched out in one long line, they would form a continuous conductor of alternate pieces of bismuth and antimony; any effect, therefore, that is produced by the difference of heat of one set of junctions to that of the other is cumulative like the electromotive force in a series of voltaic cells. Wires from the first bismuth and the last antimony complete the circuit and show any electromotive force produced by its action on a galvanometer which is placed in the wire circuit.

This last instrument (the galvanometer) is a couple of equally magnetized needles reversed in direction to each other (North above South) and suspended by a fibre in such a manner that the lower one is within a coil of wire which passes over and under it and parallel to it while it is at rest. When a current passes through the coil, the ends of this needle are driven out from the coil, in one direction or the other, according to the direction of the current.

The thermopile, when in use, is turned with one face towards, or touched with, the object of which the temperature is to be tested, and if there is any difference of heat made by doing this between the two faces of the pile, the instrument records it by its effect on the galvanometer. Very small and very quick variations of temperature are detected by this instrument, that would pass quite unnoticeable in observation with a thermometer. Passing the hand, for instance, in front of one face of the instrument, and an inch away from it, will usually send the galvanometer needles at right angles to the wire coil.

Another application of this effect of heat on junctions of dissimilar metals was proposed, but whether found efficient or not is not known to the writer. It was an invention to find the temperature of borings or other inaccessible places, by lowering into them one of the joined ends of two wires of copper and iron covered with insulating material, whose other joined ends were in a bucket of water in which was a thermometer: a galvanometer was also in the circuit on one of the wires. The water in the bucket was to have its temperature changed until the current ceased to affect the galvanometer, when the temperature of the hole would be the same as that of the water as shown by a thermometer.

There have been other thermoelectric machines made that we need not describe, as they soon became inefficient,

but one of them used materials which we should notice: they were iron and galena. Now iron and lead make a weak couple of less than a sixth of the activity of a bismuth and antimony couple, while a couple of iron and galena (which is sulphide of lead) is much stronger than one of bismuth and antimony. We should remember this when we come to inquire into the causes of production of this force.

If the heat at one junction of a couple circuit is constantly increased, the current is increased up to a certain point: then decreases till it comes to nothing: and with still higher heat is reversed, flowing in the contrary direction to that which it had before. Thus, in an iron and zinc couple, with one junction kept at 50° C., and the other increasingly heated, the current runs from iron to zinc and increases up to 200°, after which it decreases till the temperature at the hot junction is 400°, and then the current reverses and passes from zinc to iron.

If a current is sent through a conductor made of two dissimilar wires joined end to end, the junction is heated or cooled according to the direction of the current and the material of the wires. For instance if they are bismuth and antimony, and the current is sent from bismuth to antimony, the junction is chilled: if sent the other way it is heated. This is called the Peltier effect. If a wire is hotter at one end than at the other, it will be more heated by a current sent through it in one direction than if sent in the other. This is called the Thomson effect.

With some metals, increase of heat causes the difference of heat produced by the current to be increased, while with others the difference decreases. Thus copper the hotter one end is made than the other, the greater is the thermoelectric effect, that is the greater the difference of electrical heat for each degree of added combustion heat: while in iron the electrical heating effect decreases the hotter the

end is made, the more the fire heat applied the less the current heats the iron in proportion.

The measure of heat generated in a wire by any electric current is current squared multiplied by resistance $= C^2R$: and when one end of the wire is made hotter by fire than the other end, there is an additional heat added or subtracted according to the direction of the current, the measure of which is current multiplied by a force $S = CS$, in which S is a variable, increasing or decreasing according to the metal used: increasing with increase of heat in copper, and decreasing with increase of heat in iron, and of different energy in every other metal. The total heat, then, of any wire heated at one end and heated also by electricity is, fire heat $+ C^2R + CS$. So long as the fire heat continues to increase, the CS heat continually increases in one case and decreases in another.

" In iron a current flowing from a hot to a cold part absorbs heat, in copper a current flowing from a hot to a cold part evolves heat." These two metals show well the different production and different energy of S, which difference must be due principally to the different powers that these and other metals have of absorbing heat, and of radiating and conducting it. Iron absorbs heat and radiates it better than copper, while copper conducts heat more than six times as well as iron. For all these reasons the surface of a longer part of the wire is acted on in the copper than in the iron: and it is this surface action that produces the force S. So in copper more and more of the force S is produced as the heat is increased, owing specially to the quick conduction: while in the iron, due probably specially to the greater radiation, a continual less addition of surface is brought into action and the force S shows a less increase in proportion to the increase of heat.

The line representing the force S is straight in most metals, but sometimes it takes unexpected curves in the higher temperatures.

The following is a list of some metals giving their thermoelectric powers when coupled with lead which is put as neutral, because the heating of a lead wire produces no S effect. Those metals in the list that are above lead are said to be positive in action to it, and those below negative, and each is positive to the one below it. The numbers represent microvolts per degree centigrade for each metal compared with lead.

Bismuth, 89 to 97	Platinum, 0·9
Nickel, 22	Copper, 1·36
German Silver, 11·75	Zinc, 2·3
Lead, 0	Iron, 17·5
	Antimony, 22·6

"A very little impurity makes a great difference in the thermoelectric power of metal, and some of the metallic sulphides, such as galena, exhibit extreme thermoelectric power."

When a current is sent from bismuth to antimony cold is produced: and conversely, when it flows from antimony to bismuth heat is produced. Silvanus Thompson says: "It is clear that if bismuth is positive with respect to antimony, any current that may be caused to flow from bismuth to antimony is aided by the electromotive force of the junction: whilst any current flowing from antimony to bismuth will meet with an opposing electromotive force. In the latter case the current will do work and heat this junction: in the former the current will receive energy at the expense of the junction which will give up heat."

Our object is to discover what causes one metal to be positive to another and what produces the electromotive force S.

We must always remember that heat means the contraction of molecules. In the oxyhydrogen flame, nothing happens but the combination of two volumes of hydrogen with one volume of oxygen to produce, not three, but only

two volumes of water vapour: and it is this 33·3 per cent. contraction that produces the tremendous heat. In the arc light it is not the electricity that gives the heat: the vibrations of electricity are not heat vibrations: the work that the electricity does is to detach the molecules of carbon as carbon gas: they combine with the oxygen of the air, one volume of carbon gas to two volumes of oxygen, to make, not three, but only two volumes of carbonic acid gas, and it is this 33·3 per cent. contraction that gives the tremendous heat. The light is due to carbon gas molecules that have failed to meet with oxygen, and contracting become incandescent charcoal.

If there is heat in a junction of two metals from a current passing through it, it is because the current has assisted in the association of molecules, which, by the cohesive power of their mutual embrace, have contracted and given out heat. And if the current has produced cold, it is because the current has assisted the dissociation of molecules, which released from mutual cohesion expand and require heat to do so.

The following is an explanation that holds good for several couples, such as bismuth, copper, or silver, with zinc, or iron, or antimony; and zinc, or iron, with antimony; but does not explain bismuth with either copper or silver. There are, however, a number of incidental actions which complicate this matter. Similarity in oxidating power: difference of specific gravity which would make a difference in the amount of air condensed on the surfaces and in its density and activity: difference of conductivity which would cause less heat to be produced on one of the surfaces: heat, however produced, which would make a difference according as one substance was more absorbent of heat than another: molecular arrangement would no doubt also make a difference; crystallized selenium, for instance, is about a thousand million times more resistant to the electric current than iron,

and about forty-five times more active in thermoelectric action. The subject needs further investigation, and the explanation given further on is a tentative one, but probably points to the main cause of the action. It is founded on the difference of oxidizability of metals, which was, as we learned, the principal cause of difference among them in their power to produce voltaic electricity and static electricity, and hitherto we have not found any production or transfer of electricity that does not depend on chemical action. This explanation we will consider in the next chapter.

With regard to the force S, it appears to depend in the first place on the effusion of the metals: those metals that have little effusion showing no force S: and in the second place, for its varying action, on the conduction, radiation, and other properties of the metals.

THERMOELECTRICITY

CHAPTER X

CHEMICAL ACTION

When a current is sent from bismuth to antimony, it produces heat, and sent in the opposite direction, cold. The faces of the metals are covered with liquid condensed air with which their surface molecules combine slowly as oxides. The current hastens this action, and besides sets up an electrolytic tide of decomposition and recomposition in which the oxygen molecules are carried across the junctions. Now the bismuth oxide, Bi_2O_2, has two molecules of oxygen, and the antimony oxide, Sb_2O_3, has three. When therefore the current flows from the antimony to the bismuth, a slow counter current of molecular exchange flows across the junction, and the two oxygen molecules from the bismuth pass back across the border to combine with the antimony which has just released its three: they do not satisfy the antimony, which takes an additional molecule from the air, and by the contraction of this molecule when it enters into combination, heat is produced. When the current comes from the other direction, three oxygen molecules pass across from the antimony to the bismuth, which requires but two, and one of the three, being released, expands, and requiring heat to do so, the junction is chilled.

It is plain that the above action may be complicated by differences of specific gravity, of conduction, heat action, and molecular arrangement, but besides all these there is another action which has probably much to do with the production of thermoelectric force: and that is the separation of the surface molecules from solids in the same way

as the water surface molecules separate in evaporation. No name seems to have been given to this action of solid surfaces, but M. le Bon has called their vaporous emanations effluves, and to distinguish this evaporation of solids from evaporation of liquids, and to save repeated explanation, we will, in these chapters, call it effusion, which according to the dictionary means dispersion as well as a pouring out.

Nobody knows anything about this effusion beyond this, that it must be very slow and difficult in some substances, and rather quick, easy, and plentiful in others. Copper and brass seem to be very durable when exposed to ordinary influences, but if you rub either of them with a finger you will produce an odour, and you can say with certainty that, whatever else may have happened, some of the surface molecules of the metal have left it and combined with some extraneous substance to form a vapour. On one occasion somebody collected some tadpoles to experiment with, and to avoid crowding them they were put into water in two basins, one of which happened to be made of brass: the next morning those in the brass basin were dead, those in the other basin lived for several days: the effluves of the brass had made the water poisonous for the tadpoles, but no smallest trace of the metal could be found in the water. It has also been found that bacteria are destroyed in water kept in a silver or brass jug.

It is probably entirely owing to effusion that metals conduct at all after their condensed air coverings have been driven away by heat. The effluves, combining with oxygen as they expand on the surface, provide a feeble, chemically active coating that allows of the passage of some current. And it is probable also that this effusion provides the molecules that combine with the condensed air on the surfaces of cold conductors, and which cause resistance by taking from the current the work needed for their combination. For resistance is the conversion of

electrical motion to some other motion, such as heat, light, or chemical change. Heat and electricity both hasten effusion.

Looking at the list of metals given, with their thermoelectric powers, we see platinum, lead, and copper close together, and gold and silver should follow platinum. These are all very lasting metals. Even lead, though it is so soft, lasts for many years; the oxide which so quickly forms on it appears to have a preservative effect. It would seem as if these metals held their neutral position with regard to the thermoelectric force because of their want of activity in effusion: and as if their want of effusion was due in some of them to their slowness of oxidation, and in others to their quickness and their protection by their coats of oxide. As regards the oxide forming a protection, Messrs. Bone and Wheeler, in a series of experiments, found that "with metals that do not oxidize, and with materials already oxidized, excess of oxygen produces no action . . . with clean copper the composition of water from the gases H_2O is six times as fast as when it is oxidized on the surface."

*   *   *   *   *

There are some examples of the thermoelectric power which are produced by modifications of the process that we described in the last chapter, which we will now examine and in which we will find that chemical action is evidently the cause of the result.

"A warm body is negatively electrified when rubbed against a cold body of the same material." The surface particles, that is the effluves of the warm body, assisted by their heat, are more ready to combine with the condensed air skin than those of the cold body are, and the moderately heated air skin is also more ready to act: and therefore the warm body being the more active member, with higher

potential, becomes the anode: the condensed air is the electrolyte, and the cold body the kathode. The friction brings the combining molecules together quickly and forcibly, but any heat produced by the friction is a waste of power so far as the electricity is concerned.

"The interruption of circuit between the ends of two bars brings them to a white heat. The heat is entirely local and disappears when the bars are joined. The heat is caused by something that happens in the air or æther between the ends." The æther may be left out of the question, as electricity does not here produce heat directly through action with it: it is the interruption in the conductors that causes the heat. The current flows to the gap and finds, instead of the good conductor it has used so far, a layer of gases with enormously greater resistance. It throws its waves on to this resisting medium, the molecules of which transform many of these electrical waves to heat waves, which, by expanding the molecules, bring them to a condition to combine chemically, with a further production of heat on account of the combination. It is a violent combustion of the air as in the lightning flash. This mode of producing local heat is now constantly used for "electric welding," and also for removing the temper from a spot in a mass of steel where a hole has to be bored. It is very useful for this sort of work, as the heat is confined to the spot where the conductor and the steel meet, and is not spread as it would be by a fire. Steel plates for armour-clads have sometimes to be heated in this way for a bolt to be inserted, or a bar can be added by merely sending a current through the bar and the plate, and also pieces can be cut out of metal slabs in this way. There are some slight objections to the process, and it will probably be superseded by a new acetylene-oxygen apparatus, or an improved oxyhydrogen blowpipe lately brought out, both of which blow away all oxide and leave a very clean cut.

"If the ends from the positive and negative wires from the terminals of a voltaic battery are put across one another, the end of the positive wire beyond the contact becomes red hot: the negative wire remains cool." From this it is clear that the electric wave in the condensed air coating exercises some propulsive force along the positive wire, and that the propulsion is carried beyond the point where the wires meet, which can only be at a small spot on one side of each wire: and the heating of the wire is due to resistance to the electric force on this part of the wire beyond the contact: that is to say, that the electromotive force of the current that has come to this part is expended in causing chemical combination between the condensed air and the surface molecules of the wire. This experiment would also appear to confirm the idea that negative electricity is a want of electricity, for if there were a negative *force* it should heat the other wire: but this we will consider further on.

"If the ends of two copper wires be bent into hooks, and one of them be heated, on placing them in contact, a current will be produced due to the presence of a thin film of oxide on the heated wire. With two platinum wires no such effect is obtained." Platinum is neutral like lead, and in some lists the one is put above, and in other lists is put below the other: the want of oxidation of the platinum, and probably the dense oxide of the lead, make them both equally inactive. The action on the heated wire resembles the action at the anode in the voltaic cell: the acid assists the oxygen to attack the zinc of the cell: the heat assists the oxygen to attack the copper of the wire: and the current increases the effect in both cases. Without the chemical action there would be no electric action.

"If we tie a knot in a piece of copper wire and pull it tight, and hammer it if need be, and heat the wire to one side of the knot, a current will be sent through the wire

when the ends are joined to form a circuit." This is sometimes put down to molecular disarrangement caused by the knot, but it is due merely to the knot having more body for absorption of heat, and less surface for thermoelectric action than the same quantity of wire on the other side of the heating lamp. The effect happens equally well if, instead of the knot, the wire is left straight but held in a pair of pliers on one side of the lamp. The pliers take the heat from the wire and keep the further part cool, and so prevent the extension of acting surface on that side, thus giving unequal chemical action in the two directions which is all that is needed to cause a current in a circuit.

" When tourmaline is being heated, one end is positively electrified and the other negatively: while cooling the reverse: and all action ceases if the crystal is heated to 150° C." Tourmaline is a solid which has a peculiar action on light, being more transparent to light vibrations with one orientation than to those at right angles to them, but we have no authorization for supposing that any but the surface molecules of solids are acted on by electricity, or are concerned in producing it. The electricity must be produced in this case by the chemical interaction of the surface molecules with the condensed air on the surface, for when the latter is driven off by the increase of temperature to 150° the action ceases. It would seem as though the surface molecules, when they are expanding with heat, send electric waves through the condensed air in one direction, and when contracting through loss of heat send the waves in the opposite direction, but what causes this action is not known. The composition of tourmaline is very complicated, as it may contain a dozen or more of the elementary substances, and we can only guess that the temperatures at which heat causes the substances of the mineral to react with oxygen are various, and that the place of the potential unit changes in consequence.

Selenium is a substance that has a very strong thermoelectric action, about forty-five times as strong as iron: and a very strong resistance to the passage of the current, about a thousand million times that of iron: and a very remarkable quickness and amplitude in its conduction changes when acted on by light. Its resistance to electric conduction is lessened by light, and the action of the light is instantaneous. Professor Adams found that the light from a taper, at six inches distance, reduced the resistance by about an eighth.

If two copper wires are wound on a plate of nonconducting material so that they cover the surfaces in an arrangement parallel, alternate, and close to but not touching one another; and melted selenium is poured over one face so as to fill the interstices between the wires, and is allowed to cool slowly so that it may crystallize; the arrangement forms what is called a selenium cell, and if the ends of the two wires be joined to the terminals of the battery, the selenium is interposed in the circuit and will conduct the current, with more or less resistance according to the action of light falling on it. If a succession of strong lights and shadows, such as would be caused by sunlight passing between, and interrupted by, the cogs of a rotating toothed wheel, be allowed to fall on the prepared face, the current will produce a tone in a telephone. This sort of arrangement forms the basis of the telephotographs and photophones lately invented.

Selenium is a material like sulphur, but darker: light affects its surface, and the effect increases somewhat for some time and perhaps passes a little inward, but the first incidence of the light affects the surface molecules only and instantly. Selenium has a strong chemical attraction for oxygen, and the resistance it gives to the current must be, its perversion of the electromotive force from electrolytic action in the condensed air, to the promotion of the

chemical union of the selenium with the oxygen. Anything therefore that assists the selenium to combine gives more of the electromotive force to the production of the current, whether this be through the new selenium compound or through the condensed air. It would appear that in this case the current passes through the selenium compound, for though the actinic rays have been found to affect conduction in other cases, the change has been but slight in comparison with this. A particular point to be noticed is that the molecules must be in their closest relations with one another: the selenium must be left to crystallize slowly: the molecules must be naturally arranged and not in a heterogeneous mixture.

The increased action of galena as compared with lead, which has no action, is probably due to the sulphur which has a strong chemical attraction for oxygen and acts like the selenium, and would show that the force which is indicated by the letter S is due to this combination of surface molecules with oxygen.

In all the examples that we have been considering, except that of tourmaline, the voltaic arrangement is plain to see: the condensed air being the electrolyte, and the metals, or single metal with two potentials, being the nodes. The tourmaline experiment is particularly interesting. It reminds one of the working of the statical machine: the heat causes the separation of the positive and negative electricities to the two ends of the crystal, just as in the machine they are driven into the conductor and the cushions.

Meantime we see that the production of electricity by heat is due to chemical action and electrolysis. The difference of chemical action due to difference of heat produces the electricity and the particular arrangement of the wires allows the formation of a current.

CONDUCTION

CHAPTER XI

CONDUCTION THROUGH GASES

WHY are some materials conductors and others not?

"Perfect vacuum is a perfect insulator," therefore we may leave the æther out of consideration, and go on to more substantial mediums.

Let us then inquire into the activity of gases.

Schuster has found that "the discharge through gas is electrolytic," and J. J. Thomson says that "chemical decomposition is essential to gaseous discharge."

"Ultra-violet light increases the conductivity of air," the reason being that its vibrations act to produce a tendency in the gases of air, or what they carry with them, to chemical change, and the electricity finds the air thereafter more easily acted on.

Flames conduct because they are gases in the act of chemical change, and heat improves the conductivity of air because heat acts in much the same way as ultra-violet light in making the material more ready to change. Smoke also discharges electricity slowly, but surely and thoroughly, as it is largely composed of heavy gases and vapours that are slowly changing, and being sluggish in their change can only aid the electricity sluggishly. "Radiant heat from red-hot iron conducts," partly because the vibrations of its radiant heat act on the air, and partly because the iron sends into the air a gaseous emanation of iron and oxygen that electricity can act upon. "An electroscope is discharged by a flame brought near it," because the flame and the air about it are filled with active chemical particles:

as Silvanus Thompson says, "Flames and hot air from red-hot iron are good conductors on account of the chemical change going on in them."

Under ordinary circumstances gases are indifferent to electricity, and are unaffected by it, hence they are good insulators. If this were not so, telegraphy, as it is now carried on by wires in the air, would be impossible. There is, however, always a slight leakage of electricity from the telegraph wires through influence, and through convection by the impurities floating in the air, and this leakage is falsely attributed to what is called ionization of the molecules of air, while as a fact the air has nothing to do with it, for air can only be brought into action by the expense of a much greater amount of electrical force than the wire has to dispose of—such a force as that which acts in the lightning flash.

The air always carries with it some water vapour, dust, microbe germs, and the molecules which many solids and most liquids are constantly discharging from their surfaces and which mix with the air in the form of gas or vapour. Many things can facilitate and hasten this effusion of the molecules and increase their number in the air, such as electricity, Röntgen rays, the sun's actinic rays, and heat rays: and there are other things which can of themselves load the air with wandering particles, as flames, incandescent metals, radium, corrupting refuse, etc.: and these floating materials, when chemically combined and aggregated into particles, are capable of accepting small charges of electricity and then would help, by this convection, to discharge any electric accumulation, and it is even possible that if they were numerous enough they might, as it were, form a bridge that would effect the discharge by electrolytic interchange—that is, conduction—among themselves. But in none of these cases could the air itself be used in the convection, and could not be used in conduction, as it can be

brought into chemical combination only by the action of great electromotive force.

Mixed or compound gases are poor conductors at any time, in fact they are classed as insulators, and it is only when great electromotive force is applied that they can be made to conduct, and even then, if by some means their resistance is increased, they will not conduct at all. A great increase of pressure on air makes it a perfect insulator, for the simple mechanical reason that the pressure has made it more difficult for the molecules to be moved.

Pure gases are nonconductors. As an instance, hydrogen, even when a mere skin on the copper in the voltaic cell, quickly stops the action by its nonconductiveness, which is due to its being an element and therefore not chemically composable with itself. But "those gases which when heated are decomposed, or molecularly dissociated, so that free atoms are present, are good conductors"—because they can recombine chemically.

It is said that "gases (including steam) are perfect nonconductors, except when so rarefied as to allow of discharge by convection through them." But there is no convection through gases at any time, as the passage of electricity through them can only occur by electrolytic conduction: and rarefaction makes this easier by making the molecules easier to move. We must not, however, accept even this as a conclusive rule except for compound gases, for no simple elementary gas molecule can act in conduction. Before it can conduct it must become a part of a compound gas molecule, and no rarefaction or force of current can make it conduct when single: and if the current is made so strong as to force a passage through any compound gas, it does so with electrochemical conduction and not by convection.

Those who advocate ionization of gases consider their theory as proven when they succeed in forcing a current

through a gas and breaking down its resistance: or rather, apparently breaking it down, for the discharge takes place in the usual electrolytic way owing to the great force of the current detaching vapour molecules from the electrodes, which mix and combine with the gas. Very little has been done to clear up this question, but hydrides have been found in the tubes when hydrogen has been used in these experiments, and it is extremely unlikely, when further investigation has been made, that any exception will be found to the rule that a current is carried electrolytically in gases.

The amount of electricity passing in these experiments is so small, on account of the small quantity of additional vapours discharged into the tube, that an ordinary galvanometer is useless to measure it, and either an electrometer or an electroscope must be employed.

The electrometer consists of a thin slip of aluminium hung by a quartz fibre and surrounded by quadrants of brass. It is kept charged with electricity, and shows, by the movements of the slip, any addition of charge, or any increase or decrease in the force of the charge. In the electroscope a charge makes the leaf stand out, and the rate at which it sinks shows how the charge leaks away: and these movements of the leaf are, in delicate cases, observed through a microscope.

The idea of ionization is, that because a simple gas cannot conduct electrochemically, and yet has been found to carry the current in some way after it has been acted on by some particular ray, that it must do so by convection owing to some change in the molecules that enables them to take little charges of electricity from one electrode with which they dart to the other electrode. This idea has been encouraged by the fact that a strong current in a vacuum tube appears to have some effect in discharging the oxygen of the rarefied air with some force away from the kathode, but this

is quite outside the subject, as the oxygen in that case carries no charge at all.

After ionization "the conductivity of the gases appeared to be entirely due to loose detached charged particles: the conducting power did not last long, the particles clinging to the sides of the vessel: it lasted longer if there was no dust present." The loose detached particles certainly carry a charge, and would, if they reached the other electrode, deliver it there, but very few, if any, do this: they are convecting not conducting and go to the nearest solid body and stick there. Dust, whether it is metallic or otherwise, attracts gaseous molecules, and when these gaseous molecules are thus removed they can no longer combine with the air or gas in the tube, and the current is stopped.

It is supposed by the believers in ionization that the ionizing agent converts the indifferent gas molecules into eager carriers of electricity: that they are enveloped in electricity: and being discharged from one electric terminal they strike the other and unload: they move, under ordinary experimental conditions, according to the statements of even the most enthusiastic observers, at the very unelectrical rate of less than half an inch in a second, as their fastest. The cessation of the current leaves many in the field, and though they must still be charged, and must still retain their original projecting force, they abandon movement. Left to themselves they simply disappear. It is variously explained, that oppositely charged ions combine and neutralize each other: or that they give up their charges to neighbouring objects and resume wandering on their own account: or that the electric force drives them to an electrode to be discharged: but this last cannot be, as there is no slow dying away of the conduction when the current is cut off, but an instant cessation, and before they disappear they are found scattered throughout the tube and not collected at the electrodes.

What truly happens is this. There must always be a chemical change to accompany the conduction of electricity, and there can be none in pure simple gases: but with impurities forced upon them the action in these gases is in no way different to the action in the electrolytic cell. The molecules of the substances that are disseminated through the gas, and which may be called ions or any other name, are present in a state of vapour (except those collected in particles of measurable dust which does not act chemically), and when actinic rays of any sort are passed through the mixture, the components are encouraged to combine and thus form an electrolytic bridge for the electromotive force to dash across with its light-like swiftness, and the components move in two slow streams in opposite directions towards the electrodes. So it happens that when the current is cut off the last of it reaches the opposite electrode instantly, and there is none left for the molecules to get rid of. The ions disappear after a time, either through chemical change or by adhering to the glass of the tube: or they can be quickly washed away or removed in various ways, simply because they are compound molecules of vapour mixed with the air, from which they can be cleared away like any other vapour.

"Professor Thomson has measured the electric charge on the ions of gas, and finds that it is the same as that carried by the ions in solution." This is quite as it should be if we may change the wording a little and say—"has measured the conducting power of the components of gas, and finds that it is the same as the conducting power of the components in solution." For the ion, or molecule, whether solid, liquid, or gas, has the same atomic combining value, and it does the same amount of chemical change in whichever condition it may be.

A dust particle, wherever it may be, collects upon itself the condensed molecules of the vapours round it, and in our

air it condenses on it the floating water vapour, and when the collection is heavy enough it falls, combined with other loaded dust particles, as a raindrop, and it is said that no raindrops are formed without these disagreeable nuclei. Mr. C. T. R. Wilson has made an apparatus to show that "ionized air" acts in the same way that the dust in air does. The following is a description of the apparatus and of what was done with it. There is a domed bell glass that can be suddenly exhausted: this is practically all that is necessary to know about the machine, its pressure gauges and the rest of it are detail. The bell is filled with ordinary air and exhausted repeatedly, and the chilled water vapour, collecting on the dust particles, forms a fog which falls to the stand of the bell, and by this means all the dust that is in the air is got rid of: after this, although the condensed water has again evaporated and mingled with the air in the bell, exhaustion can produce no more fog, as there is no more dust to serve as nuclei to the water-drops. If now Röntgen rays, or rays from radium, or ultra-violet rays, are directed on the bell, fog is again formed when it is suddenly exhausted. This is supposed to prove that the gases have become ionized—that is to say, that their molecules have been changed to travelling carriers charged with electricity and to have become the nuclei of the water-drops.

The latter part of this supposition is patent enough. Something is doing the same work as the dust particles previously did. And if by ionized is merely meant that the molecules of the gases have been acted on by the actinic rays, and have combined to form nitrogenous or other compound molecules on which vapour can condense as it did on the dust motes, the whole supposition is right: but if it means that they have become coated or filled with electricity, it means the metaphysical introduction of an utterly unnecessary and impossible complication.

"No one doubts the material nature of the carriers in a

Crookes' tube from which all the gas has been exhausted as completely as possible." These certainly are the only carriers in the tube, but it is not at all apparent that these bits of metal are torn away from the electrode by the force of the current for the express object of being discharged against the opposite pole each with its load of electricity, for very few of them get so far, and the electric current does not use them but is transferred electrolytically by the combination of the invisible molecules of metallic and other vapours mixed with the residual air: and that this is the case is shown by the colours of the discharges in these vacuum tubes, their colours being due to radiation from gases and metallic vapours and not to any action of solid particles. Also, when the tubes are exhausted as completely as possible, the current cannot pass although the particles remain.

It is, however, very difficult to prevent electric communication, even in the most highly exhausted tubes, when large electrodes are used, but the effect is not due to conduction in the air, but to conduction on the surface of the glass, and perhaps also to influence waves, the action of which will be one of our next subjects of study.

There is an experiment devised by Hittorf which is supposed to show that electromotive force prefers to strike across a long gap rather than a short one in highly rarefied gas. "Two glass bulbs are joined at their nearer sides by a short wide tube; and two electrodes, which are sealed into their further sides, reach into this tube and have their points a twenty-fifth of an inch apart: the bulbs are also connected by a spirally arranged narrow glass tube twelve feet long. When the pressure of the air in the apparatus is reduced to a very low value, the discharge takes place through the long tube and not across the space between the points of the electrodes."

In apparatus of this sort the bulbs and the sealing patches

and the long tube are made of soda glass: and what happens when a strong current is applied and its passage is denied by the highly rarefied air inside, is that it forces a passage on the outside surface between the insertions of the electrodes, and it finds there comparatively easy conduction. Even if the machine were made of flint glass there would be no security against outside conduction, as the surface might easily be contaminated by dust or handling. The contained air in this machine had nothing to do with the action.

John Hopkinson, who was a careful experimenter, was once taken in, in much the same way. Making experiments to show that electrolytic conduction passed through glass, he put a test tube containing an electrolyte in a jar containing another electrolyte and completed the circuit with a loop of wire: there was a slight current that was much increased by boiling the liquid in the jar. But he found, or rather Lord Kelvin showed him, that the current did not pass through the glass, but over its surface. This shows how careful we should be in interpreting experiments.

"Workers are justified in using hypotheses for extending inquiry, but they need not be taken as facts," and very often "opinions are not specifications of fact but of fancies, and the more sensational they are, the better they please the mob and the more the exponent is applauded." It is most likely that the wonder-inspiring ideas of the day will by another generation be detected as absurd and futile, and their places filled by facts of pure simplicity.

It almost seems as if it were for such sensational reasons that the impossible electrical pack-carrying ion, which is so charmingly active and incomprehensible, is so constantly reincarnated: but certainly it is by no means generally accepted by men of science, as the following extracts from the address of Professor H. E. Armstrong, the president of

the chemical section of the British Association at Winnipeg, will show.

"The ionic dissociation hypothesis is a beautiful mare's nest which fails apparently to fit the facts whenever it is examined," and "the dissociation hypothesis is incompatible with facts." We shall therefore be in good company if we reject the ionization theory and pin our faith on believing—what all the facts point to—that "every case of electrical change is accompanied by chemical change."

CONDUCTION

CHAPTER XII

CONDUCTION BY LIQUIDS AND SOLIDS

We have already studied the manner of the passage of the current through the fluid in the voltaic cell, and through fluids in separate vessels in the circuit, and have found that its action is always the same when it passes through liquid, it can only do so by electrolysis: it decomposes and recomposes the molecules of the liquid.

Electricity seems to have a partiality for fluid as a conductor. We bury our earth wires where it is hoped the soil may remain damp: so also the ground ends of our lightning conductors. In the lightning stroke the current passes through the body in preference to going over the dry skin, and it does this because the blood and other fluids of the flesh are suited to its need for chemical change. The proneness to putrefaction of animal bodies after the stroke shows the electrolytic manner in which the current has been enabled to traverse the body: there is a small burnt mark at the point of entry and another at the exit, where interference has produced heat, but in the body there is no burning but only signs of chemical change.

In some cases where men have been in the rain sufficiently long to get well wetted before gaining shelter, and who have after this wetting been struck with lightning, the clothes have been torn off and there have been marks on the skin, and this has happened because the current found its preferable way through the wet clothes and over the warm wet skin.

A pine tree when struck with lightning is very much

damaged, and its bark is stripped off it. Its branches stand out square from the trunk and convey no rain to it, and the bark is rough and keeps any water that may be driven on to it in unconnected patches, and its resinous sap is a bad conductor: so it is ruined: while the beech with its more upright branches, which drain the rain on to its smooth bark that is soon wetted all over, sustains no damage because the water on the bark gives a fair channel for the discharge.

It has been considered that the wet clothes and the fir-tree bark are driven off by the formation of steam, but this is a very doubtful explanation, and we can perform an experiment that will prove to us that the force that does these things can cause action in this way without the production of any steam. "When a current is sent through a closed glass tube entirely filled with water, the glass is shattered." Because, you might say, as these others have done, that the electricity has changed the water to steam; or because, as some physicist might say, you have forced in a quantity of material electrons. But neither has been done. The resistance to the electricity does give a small amount of heat to the water, but it is so little that a thermometer is not delicate enough to distinguish it, and certainly the glass would have withstood a small pressure of steam. What exploded the tube was, that the electromotive force decomposed the water into separate liquid molecules of hydrogen and oxygen, and so for a brief instant allowed of their expansion in bulk to fifty per cent. more than their bulk when combined as water. They recombined almost in the same instant, but the mischief was done and the glass shattered by the first part of the electrolytic action of the current in passing through the water.

Water is not a very good conductor: a single Daniell's cell has not enough electromotive force to overcome the cohesion of the components of the water molecules, still two cells, or

any sufficiently strong current of any sort can always make it act, and it acts thus whether it is in the form of vapour or of fluid: but ice is a nonconductor, because, as one may easily guess, the resistance to change in the water is enormously increased by its solidification.

"Threads of silk are nonconductors, but wetted with salt water they conduct well": but it is the electrolyzed water that conducts and not the unchangeable silk.

The best fluid conductors are the solutions of the metallic salts, not because of any attraction of their metallic molecules for electricity, but because the liquid components of these salts are easily separated chemically, and for that reason are easily electrolyzed.

There are some liquids that are nonconductors, such as oils and liquid resins: their molecules are compounded of many elemental ones, so their nonconduction is not due to elemental singleness, nor is it because they are not decomposable, for a little heat can do this: but it is because the electric wave is either not strong enough for the work, or else lacks that particular vibration that can act on them and that the heat wave possesses.

Elemental fluids are nonconductors, except oxygen, which is changed into ozone by the current. Hydrogen, which is perhaps unchangeable, does not accept electricity whether it is fluid or gas.

It has now apparently been generally accepted that the conduction of electricity through fluid is effected by the method of electrolysis, but the idea was bitterly opposed at first by those who argued in favour of travelling ions with their packs of electricity and lightning speed of travel, and there are still some who are loth to discard so simple an explanation, and have modified the old ion idea, saying that the electricity forms part of the molecule which it leaves to dart through the fluid. Such a theory gives no explanation of the separation of acid and basic molecules at the

electrodes: and the motion that this ionic darting would produce in the fluid would be most tempestuous, far more violent than the most furious boiling, so, contemplating our apparently unmoved electrolytes, we may reject any such theories as false.

Those fluids only that are decomposable by the electromotive force are conductors. The electromotive force reproduces in its course through the fluid the same movement that produced itself. It impels the acid component molecule to move in one direction, and the next basic molecule takes it up and combines with it, and in this way, step by step, each wave is transmitted with great speed through the fluid conductor without the least appreciable movement of the fluid, for the movement in the material caused by each wave is only the inappreciable distance of one molecule's breadth.

* * * * *

The conduction of solids depends on several conditions, and among these their material counts most. Metals, including carbon, are the best; copper conducts about a million times better than the average electrolyte. Stones are generally bad conductors, but soap-stone is good compared with other stones.

Among metals proper, silver heads the list as a conductor, and on this account used to be taken as the standard of comparison for conduction with a nominal power of 100. Compared with it copper has a conduction of 94, iron 16, mercury 1·5, carbon one three-thousandth. The other solid elements are indifferent conductors, selenium, for instance, having only a forty thousand-millionth part of the conductivity of silver. Alloys are worse conductors than either of the metals composing them.

The conduction of metals does not appear to depend on their atomic weights, for silver being 100, aluminium is

registered at 55, and lead is only 7. Nor does it seem to be due to their oxidizability, for iron is only 16 against platinum 13. It is probable, however, that both these—the weight and the oxidability—have something to do with their conducting powers, but that more than either, the molecular condition of the surface tells. Silver is of all metals the most smooth of surface, while if one goes down the list, copper, gold, aluminium, platinum, iron, lead—each shows a decrease in smoothness, though mercury, which comes after lead, seems to give a contradiction to this idea.

Evans found that the carbon filament in an incandescent lamp gave a better light when bright polished than when dull, and that the temperature to which a dull filament has to be raised to give a definite light is higher than that of a bright one, therefore this lesser resistance of the bright filament we may put down to its smoothness. Also, experimenting with two platinum wires in vacuum tubes, one bright and the other smoked, he found the resistance of the smoked wire nearly double that of the bright one, at a dull red heat: and the tube of the "bright wire was not unpleasantly warm to the hand, while that containing the other was hot enough to blister the skin." The waves of electricity passing over the wire, in one case produced light and in the other heat. The resultant of motion was the same in both cases, but in one there was more light motion produced and in the other more heat motion. In what possible manner could corpuscular electrical ions produce these different effects?

Taking smoothness as the reason for conductivity, one could understand the falling off in this respect of the alloys, which with mixtures of molecules of different shapes for surfaces could not be expected to have great smoothness. Lead, tin, zinc, and cadmium, which are somewhat alike, have a conductivity in their alloys more or less corresponding to what may be calculated from the percentage of the

metals in their composition, but all other metals, either alloyed together or with these, show a much lower conductive power. Silver 98 parts alloyed with tin 2 parts has a conductance of 23 instead of 98·2, as it should have by calculation: and silver 10 parts with tin 90 has 11·5 instead of 20·1.

But there is this also to be said, that besides wanting in smoothness, the metals in alloys may react on one another and produce currents which would be equivalent to the polarization in the voltaic cell, and the greater the potential difference between the metals mixed together, the greater the resistance, and this difference we see above where silver and tin, which occupy places the one at the top and the other near the foot of the scale, show a great falling off in conduction in their alloys, while alloys of the other metals which are near each other in conducting power have better preserved it in the mixture. "A very slight impurity in copper wire increases its resistance." A very small quantity of impurity could have very little effect on the evenness of the surface, but would have some amount of action on an active electrolytic metal like copper. Still this does not explain the great falling off in power of alloys of the noble metals, and in them probably it is the surface change that tells.

On account of their power of conduction and their ductility, metals are the only substances used for conductors of electrical machines. Iron rusts, and other metals are too expensive or otherwise unsuitable, so copper is used almost exclusively, and on this account has lately been taken as the standard for comparison at 100: the numeration for silver and the others being proportionately increased. Iron being very cheap is used for land telegraphs, as the distances are not so long as to make its resistance an objection, but for deep sea cables it cannot be used, as any possible electromotive force applied would be worn out before the terminus was reached: so the more expensive copper which conducts six times as well is used.

Among non-metallic solid conductors hemp thread is about the best, while silk thread is a useful nonconductor. The nonconductors are not however entirely nonconducting, but have so little power of conduction that it is very difficult to measure it—less than a billionth of that of silver, and the more so because it is next to impossible to get rid of the interference of vapour and other matters in the air and clinging to the articles used. Water vapour conducts as well as water, and though its power is less than a millionth of that of silver, still it is, on account of such power as it has, one of the most obtrusive substances in electrical experiments, discharging machines in damp weather almost as fast as they are charged.

All solids, unless they are permeated with fluid, conduct on their surfaces only: so also do mercury and molten metals, but this is because these latter are elements and chemically unchangeable in themselves.

Bjerknes, when experimenting with resonators of different metals, plated (by electrolysis) an iron resonator with copper and a copper resonator with iron, and found that their actions were those of their skins and not of the contained metals. The surfaces only were used for conduction, and this points also to the condition of the surfaces as the cause of the difference in conduction.

Heat changes many solid nonconductors of compound material to conductors, and when they melt, or when any chemical change is brought about in them through the action of heat, they may become electrolytes to the current, and often good conductors. With metals, however, it is quite the contrary: they lose their power of conduction nearly always when melted, and if in a few cases some small power is left, it is still by their surfaces only that they conduct: for no chemical change can be made in their elemental substances by electricity, and without this there is no electrolytic conduction.

CONDUCTION

CHAPTER XIII

ELECTROLYTIC SURFACE CONDUCTION

ONE might suppose from what we learnt in the last chapter that we had exhausted the subject of conduction by solids, but the fact is that our examination so far has been merely introductory: we have still much to learn.

The first theory about the conduction of electricity by solid conductors was, naturally enough, that it used them as a sort of pipes. But it was very soon discovered that hollow bodies have no electricity inside them whether they are conducting or not, and that the thinnest metal tube conducts almost quite as well as a bar of the same diameter does. So till very lately the surface has been considered as the place of electric transmission, though there have been individuals who, harking back to old fancies, have made measurements of the depth to which the electricity soaks inward. But latterly a theory has been brought forward that the electric current is transmitted through the medium surrounding the wires, and does not use the wire in any way except as a sort of clue to give it direction.

It is a pity that statements should not be made with as great clearness as possible, instead of being given to us disguised in words which may have several meanings. There is nothing definite about the word medium. If in this case it means the æther, then the idea is wrong, for a vacuum which contains æther and nothing else is an absolute non-conductor: and a wire heated red hot and cooled in hydrogen is a nonconductor, though there is plenty of æther with the hydrogen. It is idle to suppose that the air is meant as the

medium, for if the current acted on the air the electricity would be dissipated at once: and thc same objection applies to anything conceivable mixed with the air. And it does not appear possible to explain on these terms conduction through a surrounding medium. How is it that the wire, if too thin, becomes heated, and may be entirely burnt away? Or why is one sort of wire a better clue than another? So we will not pursue this new theory, but study the arguments for and against surface conduction.

The fact that copper wires used for carrying electric currents are made brittle is quoted as a proof that the current passes through the body of the wire. But the mere heating and cooling of this wire will make it brittle without any help from electricity. It may be that absolutely pure copper would not be affected either by temperature or by electricity, and that the effect shown is due to the heat caused by the current aiding the impurities to separate from the copper: a very little impurity greatly increases the resistance in copper wire. Brass wire, if kept for any time, whether used or unused, becomes brittle and useless. In some experiments which were made to observe the effect of heat on cast iron, although the heat was not pressed above a dull red, it was found that the carbon inclined to aggregate, and it is quite comprehensible that if a body is made up of a mixture of two or more sets of crystalline molecules of different shapes and unlike facets, that when expansions and contractions occur in the mixed mass, the adhesion of the unlikes would be shaken if one of the material molecules should expand or contract more or sooner than the other, and that the likes should collect together with a bad effect on the solidity of the mass. There is an alloy which is called invar, from its remaining unexpanded by heat; in it we must suppose that there is a constant struggle going on between the different sets of molecules, and it is to be anticipated that it will fail through this. However this may be, it

would seem that the brittleness of the copper wire is not necessarily a consequence of its use as a conductor, but rather is due to its want of purity.

"Heat increases the resistance of pure metals." Take a piece of thin wire of pure silver for the conductor between the zinc and copper of a cell, and roll the middle of it into a spiral just big enough for a round iron bar—a poker, for instance—to go through easily: heat the end of the poker red hot and pass it into the spiral while the cell is working, or heat the spiral with a spirit lamp: the current is stopped. Remove the bar or lamp and the spiral cools very quickly, but not for some time after the wire has become cold is the current re-established. The wire lost something because of the heating, and it does not seem as if the surrounding medium had anything to do with this: for allowing that heat could drive the medium away, there could be nothing to prevent its acting again immediately the wire is cold.

Solids conduct on their surfaces only. Take a rod of common soda glass and twist the positive and negative wires of a battery round its ends so that it forms part of the circuit: it acts as a conductor, though not well; wetted with water it conducts better. Now dry it and pass a spirit lamp flame several times along it, and though it is not hot, it is a nonconductor and remains so for hours. It will not do to use any sort of flame for passing over the rod, it must be a clean flame, for soot is a conductor and is difficult to wash off.

Try the same experiment with a flint glass rod. At no time is it a conductor, not even when wetted with water. Examine the wet surface with a magnifying glass and you will see that the water has collected in separate little patches—they have no continuance. But none of this could interfere with the conduction in a surrounding medium. There was something on the common glass that conducted, and a skin of water made it conduct better:

and whatever was on the surface was driven away by heat, and afterwards the glass would not conduct, though its substance was in no way changed. Then again the water on the soda glass had a continuous surface and conducted well, and on the flint glass, having no continuity, did not conduct at all. And the medium round the rods had no influence or connection with the conduction.

It is a pity to spoil a good flint glass rod, but you can try the following experiment if you will not accept it without personal experience. Make the surface rough in some way; scrub it with emery cloth and you will see plainly that it is rough: or soak it in strong solution of washing soda and you will not know that the surface is changed till you come to use it. Whichever you have done, rub the rod with fur and you will find that it gives negative electricity instead of positive. Wash it, dry it, and clear off the electricity with the flame of a spirit lamp, and try it in an electric circuit: it is a nonconductor. Wait for a few hours and try again: now it conducts, poorly certainly, a good deal worse than water, but just as well as the soda glass rod, and when wetted it conducts better, and the magnifier shows us that the water is not in separate patches, but forms a continuous skin. Dry it again, and pass the flame along it and its conductivity is gone. This glass has not been changed in any way except as to its surface, and the surrounding medium has not been interfered with: so we may say that the inner substance of the glass has certainly had nothing to do with the carrying of the current: nor surely had the body of the silver wire: nor the body of the other glass rod: nor the air or other medium round any of them.

When this spoilt flint glass rod was recovered from its loss caused by the flame, it picked up something on its surface similar to that which the other rod had: most likely the same that the silver wire had. What could they all

pick up under the same conditions but the same thing? Something that they got from the air, for nothing else touched them. Something that formed a continuous skin on their surfaces and which alone carried the current. For without it, neither the surrounding medium, nor the surface of the conductor, nor the material body of the conductor, had any power to conduct the electric current.

If a conducting wire is cleaned, heated, and allowed to cool in hydrogen or carbonic acid gas, it remains a nonconductor. Messrs. Bone and Wheeler, by experiments described in one of the transactions of the Royal Society, lately published, have shown very clearly that hydrogen is plentifully condensed on the surface of metals immersed in the gas, and such is also the case with other gases: so it is not because it has not received a coating of condensed gas that the wire refuses to conduct, but, either because none of these gases can combine with the metal surface to form an electrolytic conductor: or because (the metal having no action) the gases are themselves nonconductors, which is truly the case.

"When a wire is allowed to cool in pure dry air, the wire becomes a conductor." Thus eliminating moisture, which we know is a conductor, we are obliged to come to the conclusion that condensed air, either of itself or by combination with the effluves from the metal or other surfaces, is the conducting agent on the wire or other surfaces.

Selenium is a very poor conductor, but light falling on it makes great changes in its powers in proportion to the changes of the light. The change is instant and has been used to give a varying current in telegraphy that reproduces pictures, such as photographs, at the receiving station: they are not, to be sure, such as one would use to decorate one's room with, or to remind one of beloved ones, but recognizable and worth keeping as curiosities. Now this change of current could not come to pass if it was the sur-

rounding medium that was acted on, for the change is plainly due to the material or what it has on its surface, and the medium, whatever it may be supposed to be, is present whatever substance may be used, but no such action occurs with any other material so far as we know: and again, light does not penetrate below the surface of opaque material: so here we are again brought back to our old landing-place, the surface of the conductor, and here we have it plainly indicated that the surface material and the air condensed on the surface are both accessory to the action on selenium. But are they both necessary in other cases? That is now the question.

We should say that both are not necessary so long as the air skin is sufficient for the work. "When a conducting wire of an alloy is placed between the poles of an electrolyte, none of the constituents of the wire are found at either pole." This happens because the wire is not the conductor, nor ever could be so long as there is an electrolyte surrounding it, for this is not only more easily acted on than the metal surface, but is ample to carry the current. And so it would be if a wire of sufficiently ample surface were used as a conductor in air: the wire would not be the conductor, nor be acted on by the electricity, but only the ample skin of air that the wire carried. When, however, the wire is thin and not sufficiently ample in surface, we see it heated and consumed, because its surface is then called into action, and it is acted on both chemically and by the heat due to the chemical action induced by the current.

The conductance of selenium is very small: ·00,000,000,025 compared with silver's 100. Silver has no appreciable interaction with pure air and gives little resistance: iron has some interaction, lead more, and selenium apparently a great deal: and in proportion to their interactions so do the resistances seemingly increase. So evidently if a free path is wanted for the current it is best to avoid any interaction

between the metal and the air: that is to say that oxidation of the conductor is a disadvantage because it gives the electricity more work to do, and that it is more to the current's advantage to leave the work of conduction to the condensed air only.

We see, then, that what concerns conduction on solid material is its surface and its oxidizability. Smoothness of surface is an advantage: there is nothing to prevent the continuity of the liquid air covering, or obstructing the propagation of the wave. Oxidizability is a disadvantage: it sets up local action and causes resistance and waste of power. Cold reduces resistance: it binds the molecules more strongly together and so makes them more secure from oxidation or any other separating force, and it probably increases the quantity of the condensed air on the surface. The less the air skin is interfered with the better the conduction: and when the condensed air is ample for the purpose it is through it alone that the transmission is made.

Skins of other simple gases will not act: a simple gas like hydrogen condenses fast enough, but it refuses to transmit because it cannot change chemically. What, then, is the action of the air skin? The condensed hydrogen refuses to transmit because it cannot combine with itself: the condensed air is a fluid made up of a mixture of oxygen and nitrogen, of which the first can combine with itself, and the two can combine together. Can anyone doubt that the action is electrolytic? It is by the combination of the oxygen with itself as ozone, and by its combination with nitrogen, that the current finds its road, and if you want confirmation of this, you will find it whenever the spark forces its way through air, when you will find that these substances are produced in such quantity as to be strongly perceptible to smell. The liquid particles of air on the conductor are acted on by the electromotive force in the same manner as the liquid in the voltaic cell is acted on:

they are dissociated and combined by every wave of the force, and so transmit the current.

Electrolysis is in this, as in all other cases that we have examined, the road of electricity. Without chemical combination we have found no conduction: without fluid there has been none: fluid, or its vapour, appears to be the electric medium, and chemical action in the fluid or vapour its means of transmission. There is no conduction of electricity in solid substances whether metallic or otherwise.

CONDUCTION

CHAPTER XIV

NONCONDUCTORS

We have settled our ideas about conductors, but have hardly mentioned nonconductors, and so far as we can gather from books on electricity and what we have ourselves seen, there seems to be little to be said about them: at any rate little has been said, and they seem to have excited scarce any interest. Still they form a part of our subject, and we ought to know what we can concerning them and their want of conduction, and we may perhaps stumble on something worth knowing in the search.

The following is a list of nonconductors taken from Professor Silvanus Thompson's well-known book. Vitreous, such as glass and slags. Stony, as slate, marble, stoneware, steatite, porcelain, mica, asbestos. Resinous, as shellac, resin, beeswax, pitch, gums, bitumen, ozokerit. Elastic, as india-rubber, gutta-percha, ebonite. Oily, as oils, fats, paraffin, paraffin oil. Cellulose, as dry wood, paper, fibre, cellulose.

"It is the nonconductors on which electricity does not spread that can be charged with electricity." Quite so, but why does it not spread?

The first thing that strikes one is that the substances named in the above list are all compound bodies: bodies in which the surfaces are made up of particles of different shapes and powers of cohesive attraction: surfaces on which one set of molecules of superior attraction might draw to themselves all the condensed air or deposited vapour, leaving the other molecules wanting, and so

producing a discontinuity of conducting surface. "Flint-glass when polished is not hygroscopic, and is a very perfect insulator: with the surface roughened its insulating power is lost. Common glass is slightly hygroscopic, and not nearly so good an insulator." This is probably a hasty explanation, made to explain a fact which was of small interest to the writer of the extract, and made without sufficient examination.

Bacon says, "Argumentum non sufficit sed experientia," and Messrs. Bone and Wheeler by some experiments regarding the combination of hydrogen and oxygen condensed on metal and other surfaces, the details of which were published in the transactions of the Royal Society, have given us some "experientiæ" which are instructive on certain points connected with our subject.

They say, that "whatever may be the mechanism of the surface action, the gas actually lying in the surface is in a different condition from the main body of the gas, and that this condition is more favourable to chemical interchanges. A spiral of platinum will ignite electrolytic gas (hydrogen and oxygen) at 90° F. It is made more active by having its air skin removed before introduction to the gases. Finely divided silver will combine the gases at 270° F., and gold at 470°. Other substances, as charcoal, pumice stone, porcelain, rock crystal, and glass, require temperatures approaching 630°." It is plain that cohesion is the active power in these cases. The solid wire has more attraction of cohesion than the silver grains, these more than the filmy gold, and the gold more than the other substances on account of their inferior density. Surface probably only acts according to the quantity of cohesive attracting power of the substance it covers, and not according to its own extent, otherwise charcoal and pumice would surely be the most active.

The dense platinum puts so much pressure by its cohesive

force on the condensed hydrogen and oxygen, that with the assistance of a heat such as we sometimes have on a summer's day, it compels them to unite: while the light-bodied charcoal has to be assisted by almost a red-hot temperature.

This draws our attention to another particularity of the nonconductors, and that is that they are none of them very heavy substances, all except the stony and vitreous being lighter than water. Consequently they attract a smaller quantity of air to condense on their surfaces than the heavier metals do, and should therefore be on this account inferior conductors.

"Platinum foil, rendered active by any of Faraday's methods, will absorb oxygen but not hydrogen." There is no difference of surface to account for this, but what does account for it is the difference in atomic weights of the materials, and as a consequence, in their combined powers of cohesion. From its greater density, the oxygen has sixteen times the cohesive attraction for the platinum that the hydrogen has: the combination of the attractions of oxygen and platinum is sufficient to condense the oxygen to liquid, but the combined attractions of hydrogen and platinum cannot reduce the hydrogen: and except as liquid the gases cannot become attached to any surface. So we may conclude that want of cohesive force tends to produce nonconduction by lessening the amount of condensed air on the surfaces.

All metals—probably all substances—constantly discharge their surface molecules as vapour, and this effusion is increased by heat and electricity. It may appear strange that the metals are not observed to diminish on this account; but they of all substances have the greatest density and therefore the greatest cohesion, and this would restrain their effusion, and molecules are very small things, and even radium, which owing to its composition is very active in this respect, lasts, so the scientists say, for several hundred

years, although to start with it may be a piece no bigger than a mustard seed. The effluve of silver is greatly increased by heat: also its combination with gases. Hydrogen is absorbed at a red heat, 650° F., by solid silver, and a hydride of silver is formed, and it may be that the increase in effluve action is due to this chemical compound becoming volatilized. This would explain the passage of the spark in tubes containing hydrogen, the gas combining with the metal of the electrode would enable the conduction to be electrolytic in this case as in all others. In all of Geissler's tubes the colouring of the light given off depends on the gases, and on the metals used for electrodes, which shows that in these tubes the contents do not remain pure gas, but have become a chemical compound in which electrolytic conduction can act. It also shows that the effluves of the metals have become gas.

Now the combination of the hydrogen and metal is a combination of but two elements, and their electrolytic movement of conduction has been forced on them by the current. But an ordinary current cannot make the oils conduct: and from this we might argue, that the oil mole cule is preserved from the dissociating action of the electromotive force because it is composed of a great number of various molecules, the combined cohesive power of which is too strong for the force to break down; and that the reason why the oils are nonconductors has nothing to do with their surfaces, but only with their inactivity as electrolytes.

To return to the glass rods. There seems to be no reason for supposing that the condensation of air on the glass rods (temperature being left out of consideration) is due to anything but the cohesive attraction between the glass and the molecules of air: or that one glass condenses more than the other: or that the roughening of the glass makes any difference in this respect. So we may safely work on the

supposition that the rods condense equal quantities on their surfaces, or if there is any difference at all, that it is in favour of the heavier glass, which is the flint, and which is the much surer nonconductor of the two. The only cause of difference in their actions seems to be, as we noticed before, that there is a different treatment of the condensed fluid by the different surfaces.

When we examined the wetted flint glass with a magnifier, we saw the little separate blobs of water scattered over the surface: and we expect that this glass acts in the same way with the particles of air or other vapours condensed on its surface. Flint glass is a mixture, not a compound, of the silicates of lead and potassium: the atomic weight of lead is 206·9, and of potassium 39·15, which means that the lead ingredient would have five and a quarter times more cohesive attractive power than the potassium ingredient. Soda glass is a mixture principally of silicates of sodium, calcium, and iron, of which the atomic weights are 23·05, 40·1, and 55·9: so that the difference of the attractive powers of the most differing ingredients is only about two and a half, and there is an intermediate attraction to act both ways and so help to an even distribution and a somewhat continuous air skin, and this is that which no doubt gives the soda glass its slight power of conduction.

We have been taught two things by that little instrument used in wireless telegraphy—the coherer—one is that a very small interval will destroy conduction, and the other is, that the air skin condensed on the surfaces of metals must itself possess a skin. When the coherer is tapped, we can see no difference in the contents of the tube: it is just an inch of glass tube filled with filings: but since the tap the current has ceased to pass, though we could declare that the filings touch each other just as closely as they did before. It is the invisible and ultratenuous skins of their air coverings that touch, and, remaining unbroken, prevent the air

coverings from mingling and making a continuous conductor. When the commotion of an induction wave shivers these skins, the condensed air coverings join and the current is then conducted through the continuous condensed air conductor.

The filings have nothing to do with the conduction beyond attracting a covering of the gases of air which is condensed and spread with its skin over each piece. It is this condensed air only that conducts, and being on metal, it is probably a thick coating because of the great cohesive attraction of the metal. If, then, a little tap can separate these coatings and isolate them, does it not seem as though the thinner coating on the flint glass might very easily be broken up and drawn away from the less attractive particles to form drops, each enclosed in its insulating skin and attached to the denser particles?

If we examine what is known about other fluid, in this connection, we may be able to form some idea as to the formation of the skin, and we will take water as our sample liquid, because in fact it is practically the only liquid that has been experimented with, and because several very charming experiments have proved beyond any doubt that it possesses a comparatively tough skin, about the formation of which however, curiously enough, no one seems to have made any attempt to theorize. This lack of energy was probably due to the theory, held a short time ago, of the condition of matter as being composed of molecules that were isolated quivering points, an impossible conception that would choke off the boldest investigator: but this idea has died out, and we may assume, what must really be the truth, that the molecules of all liquids are minute globes in close contact. In the interior of the liquid every molecule, by cohesion, attracts and is attracted by every molecule touching it: but at the surface, where the water is in contact with the air, the water molecule must find that practically all its cohesive attraction is towards

the water below and alongside of it, because the air molecule, which is seven hundred times its size, has only a four-hundredth as much cohesive attraction towards it as the water molecules each have to each other, and we may conceive that the surface molecule is flattened out by this force into a hexagonal scale, and that these scales form the surface skin. Now, if this is fact—and it is surely reasonable enough—the condensed air forms its skin in the same way: and when the air condenses on metal surfaces, the strong cohesive attraction of the metal draws down all the liquid air molecules equally towards it, so that there is an even deposit and no gaps in the skin: but on a surface made up of particles some of which have more than five times the attraction of the others, the air would first condense on the more attractive particles and there form a drop with its skin, and afterwards, though the drop could increase by taking in more condensed air molecules, it could not join with its neighbours, and there would be no continuity in the coating, and it would be a nonconductor.

There is, however, no way of proving this, but we can surely agree that it was because of a partly continuous skin on the soda glass, and a skin in separate beads on the flint glass, that the one conducted and the other did not: and that this is the difference between any conductor and any non-conductor, that the one has a continuous skin of air condensed on its surface, and the other a similar quantity, perhaps, but broken into discontinuous patches.

The popular conception of the conduction of electricity is, that the electric fluid pours through the conductor in the same way as water is discharged in a gutter or a pipe; but examination shows that nothing of the sort occurs, and that we must come to these conclusions: that conduction on conductors is due to the electrochemical action, called electrolysis, of their air skins, and that any action of the metal is not only unnecessary but detrimental; that the

difference between solid conductors and nonconductors is the continuity of the air skin on the one and its discontinuity on the other; and that fluids or vapours alone conduct, and conduct by electrolysis alone.

Conduction is not a rush of material, corpuscular, electronic, or other, through a conductor, but an instantaneous transfer of vibrations over possibly great distances, with molecular electrolytic interchange through infinitely small spaces in response to each vibration.

RESISTANCE

CHAPTER XV

ELECTRICAL RESISTANCE IS THE OPPOSITION BY CONDUCTORS TO THE ELECTRIC CURRENT

"WHEN a current does work it is at the expense of the current."

Since the current, wherever it passes, is carried electrolytically, it must do this electrochemical work whether it is in a cell, or on a machine, or on the wires beyond them, but in commercial installations the work lost in the generator is small and no separate count is kept of it, and resistance means to the electrical engineer the resistance on the conducting wires outside the generating-house, and however good the conducting power of the wires may be, there is, even in the best of solid metallic conductors, a good deal of action of the material of the conductor beside the necessary electrolytic work in its air skin, and to overcome this interference of the material the current must do work and lose force which, with a perfect conductor and no interference, would have carried the current much further. What we have to examine is the resistance made up of all the work done by the current.

The stronger the electromotive force, the further the current will go: the greater the resistance, the sooner will the force fail to act. We must remember that the strength of the electric wave does not depend on its quantity, but on the vigour with which its impulses were originated: a great wave of electricity without vigour would not travel any way near so far as a smaller, violently produced wave.

"Doubling the length or halving the cross sectional area,

doubles the resistance and halves the current." This is true both of the resistance in a cell and on a conducting wire, and because the doubling of the cross section of the wire does not double the surface area of the wire, while it doubles the possible current, it is brought forward as an argument to prove that the current must pass through the substance of the wire, which as they say is the only thing doubled. But it is not so. There is certainly twice as much metal in the same length of wire by doubling its sectional area, but this doubling of the material brings the material into a relatively nearer position to the axis of the wire, than the material of the smaller wire, and it is therefore able, on account of its better position added to its double quantity, to exert fully twice the cohesive attraction of the smaller wire, and to collect on its surface fully twice the amount of condensed air, and to convey by this means fully twice the amount of current. So instead of being an argument in favour of the idea that the material of the wire conducts, it is a proof of skin conduction on solid conductors.

If a conductor has not sufficient surface or is too long, its resistance is increased and only a feeble current passes. A part of the current that might have been generated in the cell, or the machine, and sent over an ample conductor, is not developed, and a part of that sent is changed to heat: and "the greater the resistance the greater the heat," and the waste consequent to it. To increase the electromotive force without increasing the capacity of the conductor will certainly cause some increase of current delivered, but at the same time it will waste a much increased quantity of current in producing heat.

If a current is sent on a wire which is so long that its resistance prevents more than a half of it from passing, there will be some heat in the wire: but if the wire is halved, although the resistance is also halved, the heat will be much greater, "because the current runs so much the stronger,

and the heating of a conductor is *quadrupled* by doubling the strength of the current." The heat is not measured by current multiplied by resistance, but by current squared: C_2R is the measure of the heat. So unless the conductor is ample to conduct all the current possible, shortening it will induce more current to be produced and to pass, but because of this will increase the waste by heat.

Resistance depends on the material. If a piece of fine silver wire and a piece of platinum wire of the same gauge be put consecutively in a circuit, the silver wire remains cool while the platinum becomes heated: for it has not more than an eighth part of the conducting power of silver, that is it resists the current nearly eight times as much. And if the current is made stronger, this metal, so difficult to melt or oxidize, may be burnt away: the current has found the path offered by the condensed air on the platinum obstructed in some way.

Lord Rayleigh found that in the case of a mixture of metals there is a source of something, which he says cannot be distinguished by experiments from resistance, which is absent in pure metals. It is in reality resistance, and there is resistance always in conductors whatever their material, and it varies according to the material of the conductors: and as the conduction is on the surface, and in the air skin on the surface, it is there that we must look for the cause of the resistance.

Nonconduction we may call absolute resistance, and it is due to a discontinuity of the air skin on the nonconductors: and there is no difficulty in supposing that the more continuous the skin the better a conductor would conduct.

The resistances of pure metals to conduction as compared with one another—say platinum with silver—must be due to difference of smoothness of surface, because the denser platinum attracts a deeper air skin and should therefore be a

better conductor; but because its covering is spread over peaks and furrows, and because the current, with its impetus to go straight, dashes from peak to peak through the more resistant intervening medium of uncondensed air, rather than dip into the hollows of the rough surface, the resistance is increased, and heat results as a consequence of the combustion of the air: this is the cause of the heating of a platinum wire on which the air skin is continuous but uneven, while a silver wire, which offers a conductor of condensed air both continuous and even on its smooth surface, remains cool though carrying the same current.

In mixed metals, neither would the surface be smooth, nor would the air skin lie evenly, and also would accumulate in denser patches on the denser material, both tending to unevenness of conduction and to resistance.

"Narrowing the conductor increases the resistance and causes heat." The condensed air on the narrowed conductor is not sufficient for the current, and the superfluous current compels some of the metal surface molecules to combine with oxygen or other material, and by their contraction in combining they produce heat.

Heat increases the resistance of pure metals: it first drives off their condensed air coverings, and then makes it more difficult for the oxygen of the air to get near and combine with them. Generally speaking, the resistance of metals above red heat is increased about forty per cent. for every rise of a hundred degrees centigrade: and advantage has been taken of this for the construction of instruments for measuring the heat of furnaces: the heat is calculated from the resistance: the greater the resistance to the passage of a current of a known strength, the greater the heat. Also, strangely enough, the same principle is applied to instruments for measuring those heats that are almost imperceptible, such as that of the moon, which, except with Professor

Langley's bolometer, is not discoverable. But then the bolometer can measure the heat of a candle two miles away!

"When metals are cooled in liquid oxygen their resistances diminish greatly. Dewar and Fleming find all pure metals to lower their resistance as though at the absolute zero of temperature they would become perfect conductors. Alloys, however, show much less change." The cold increases the solidity, as we may call it, of the metals. Just as ice at freezing evaporates from its surface and does so less and less as it becomes colder till, at a certain low temperature, it can give off no vapour because the attraction of cohesion of its molecules to one another is too strong for the heat, at that temperature, to overcome and separate them: so the cohesion of the metal molecules is increased by the increase of density given to them by contraction due to loss of heat, and they are no longer free to mingle and combine with the condensed air and obstruct the current by setting up unnecessary action. Also the molecules of the condensed air are perhaps made to be more ready to combine and to relieve the current of some work. That the resistances of alloys are less changed is a proof that they retain their interaction with the current. Their mixed molecules of different shapes must be less controlled collectively by cohesion, as their want of fit prevents any closer touch being brought about by their contraction due to cold, so their individual freedom is less interfered with, and they continue liable to be moved by and to obstruct the current.

"The resistance of carbon, on the contrary, diminishes on heating. The carbon filament in the incandescent lamp has five times the resistance when cold that it has at a white heat." This substance holds the happy position of having a moderate resistance to conduction of electricity —about three-thousandths that of silver—and almost an indestructibility in the absence of oxygen, which together fit it specially for use in electric glow lamps. Most metals

in the same position would melt, but carbon, though it can so easily be turned to vapour and to liquid when combined with oxygen, has never yet been melted. We cannot speak with certainty about the way in which it gives light in the incandescent lamps, but one of the experiments tried with the voltaic arc gives one an idea. "The light of the voltaic arc is due to the incandescence of the carbon particles thrown off by the poles. The heated air is dark." The carbon combines as gas with the oxygen of the air to become carbonic acid gas and is used to electrolytically convey the current. But "the negative carbon point instead of diminishing grows in length when burning in coal gas." Here the carbon gas is not combined with the oxygen and yet gives light. The current finds it easier to promote the combination of the hydrogen and oxygen, than that of the carbon and oxygen, and as the combustion of the hydrogen and oxygen gives no light, it is plain that the carbon which was gas becomes solid carbon, and in contracting to do so becomes incandescent—that is, produces vibrations of light. So we may say that the surface molecules of the carbon filament are changed to gas by the action of the electromotive force, and that immediately on their liberation they contract to solid incandescent carbon molecules.

Regarding the light and the conduction of the filament, we have the following facts to consider and to base an opinion on. Carbon occludes air in large quantities: the effluves of substances leave their surfaces as gas: carbon gas immediately condenses to solid even at our highest producible temperatures: if we examine the bulb of a burnt out glow-lamp, we find the carbon that had formed the filament spread over the lower part of the bulb—it has not been changed to carbonic acid gas: heat encourages the effusion of surface molecules. From these facts we may draw the following conclusions.

The occluded liquid gases in the carbon filament furnish the electrolyte for the transmission of the current: the liquid gases are forced into combination, and contracting in doing so produce part of the heat of the filament: the rest of the heat is due to surface resistance: all the heat is used to expand the surface molecules to carbon gas: these effused carbon gas molecules immediately contract to solid carbon molecules, in doing which they produce an amount of light vibrations almost equivalent to the amount of heat vibrations expended on their expansion: there is little difference in these amounts, so there is little heat manifested under ordinary circumstances, and the bulb is not much heated.

"Solid insulators decrease their resistance enormously on heating, and when they begin to melt, or when any chemical change occurs in them through the action of heat, they generally are made to act as electrolytes by the electromotive force, and they become good conductors." This refers, not to metals, but to compound solids, and we must make no mistake about this, as neither metals nor their alloys conduct electrolytically either when solid or when melted. The compound non-metallic substances become liquid electrolytes when melted, and their resistance to the current depends on the strength of the chemical cohesion of the substances composing them, and whether the electromotive force employed is sufficient to separate their component molecules. But elementary non-metallic solids, like quartz for instance, do not come under this rule: fused quartz is an absolute nonconductor.

"A current divides among various paths according to their easiness." The current may prefer to spark across a gap rather than go the round of a long loop, or force its way along a fine wire. It finds it easier to produce electrolysis in the air gases in the gap, than to overcome the resistance to the same action in the fluid air on the longer or

too narrow track. When the spark leaps across, all the electromotive force available is used to produce the effect, and there is no current left. And when several conductors are available and are together sufficient to carry the whole current, it divides among them, the more of it going where there is the lesser resistance.

Liquids have different resistances according to their composition, and at the best are only moderately good conductors. Water offers a good deal of resistance when pure; indeed it has been stated that pure water is an absolute nonconductor, but probably every compound fluid can be forced into conduction if enough electromotive force is applied. When the water holds salts in solution there is much less resistance, and it is due to the greater ease with which the chemical interchanges can be effected in the dissolved salts than in the water which has dissolved them. But in the best of electrolytes as compared with copper—that is to say, with the fluid air on copper—the resistance is very great, and it is greater where there is no mineral in the solution: in nitric or sulphuric acids, it is at the least a million times that of copper.

"Fluids are bad conductors of electricity. As all cells are worked with fluids separating their plates, there must be some internal resistance. Therefore in considering the resistance, the internal resistance of the cell must be added to the external resistance of the conductor." Seeing that the resistance of the machine cannot be avoided, the only occasion for measuring its resistance is when comparing different machines: beyond this the external resistances of the circuit are all that practically call for attention, and these only in long circuits such as those used for tramways and electric lighting: for the short circuits on ordinary wires of domestic use and laboratory experiments, there is practically no resistance.

Mixed gases convey by electrolysis in the same way as

fluids, only they give much greater resistance. When an electrical machine is worked, the current does not pass in a continuous stream between the electrodes, but in separate sparks: a sufficient electrical force has to be provided each time a spark passes, before the resistance of the air can be broken down, for the air gases have to combine before the current can use them, and it is very much more difficult to make their molecules combine as gas than when they are condensed as fluid on a conductor; indeed it is probably as fluid that the gases combine when the spark passes, though they immediately afterwards become vapour, being vaporized by the heat that they have themselves produced by their contraction on combining. The electromotive force puts a strain on them that brings them into a condition to combine: they join contracting to fluid dimensions, and also contracting from chemical intercohesion on combining: and the heat produced by these contractions expands them again to vapour. The first contraction, which is the more violent, produces the heat, light, and actinic vibrations of the spark; the subsequent expansion is nearly equal to it, so but little heat is made sensible: the contraction on chemical combination is the part of the process used by the current.

The resistance of the elemental gases and vapours should be absolute, as they should not combine with themselves, and no conduction can occur without combination: but oxygen does combine with itself, and it is not certain that other of these substances do not do this also. Whatever may be the case, all gases and vapours offer great resistance.

Resistance, then, may be occasioned in several ways, but in every case it is due to a diverted action of electrolysis.

DISCHARGE

CHAPTER XVI

ELECTRIC WIND AND GLOW DISCHARGE

If we electrify an insulated body and leave it to itself, after a time the charge disappears, it is dissipated, and the body is discharged.

Some of the charge always manages to leak by conduction over the surface of the support, which, whatever its material may be, is not in itself an absolute nonconductor, and also the support collects on its surface dust and damp both of which conduct, and it may have been carelessly cleaned and scratched, and the scratches form conducting channels.

Some of the charge is conveyed away through the air. Perfectly dry and clean air does no convection, nor any conduction except under pressure from exceptional electromotive force. But the atmosphere is never naturally perfectly dry or clean, and its dust particles, and perhaps its vapour, take little charges which they convey away from the electrified surface.

If there is any point or angularity on the body, it will discharge the electricity quickly. The electricity seems to be driven from the point as a wind: and this wind draws the vapour and dust-laden air over the electrified surface, and the floating particles take their small charges and fly away to discharge elsewhere. If the body has no points, the main part of the charge is lost through induction, which is a phenomenon which we will consider separately in another chapter.

In whatever way the charge may be dissipated, its loss is from quick to slow like heat: the more nearly the body is

exhausted, the more slowly it gives up the last remnant. But this is almost the only resemblance that there is between electricity and heat, and it is only in the case of insulated bodies that there is this resemblance: and the cause of the resemblance is that in both cases the molecules have been put under a strain from which they recover vigorously at first, and after that more and more slowly. It is only in this effect, however, that there is resemblance, for the strains are quite unlike. Heat expands the molecules and their cohesion of composition contracts them: electricity puts an electrolytic strain of separation upon the components of the molecules which their cohesion of composition opposes.

There is probably never any conduction of electricity from a small insulated charged body in air except over the support: it is only where there is a large densely charged body, like a mass of cloud, that the atmosphere can be forced to become an electrolyte and to provide a conducting route for the discharge. The air then conducts in the same manner as the fluid in a voltaic cell: it is composed and decomposed along the track of the current, and the result of the burning of the air is left in the current's track. It is the same also with the spark from a machine: it leaps across the gap, forcing the air into that chemical combination without which conduction is impossible, and the contraction of the combining molecules produces the vibrations of the light and heat of the spark. It is these violent passages and those more silent ones from points that are what are generally meant when discharges are spoken of.

It is not necessary to say more about the silent electrolytic leakage on the supports, or convection by dust and damp, so we will go on to examine the other modes of discharge, beginning with that from points, which varies from what may be called a quiet leak to a bright fizzing brush.

If we fasten a needle, by its head, to the conductor of a

working electrical machine, or a charged Leyden jar, or electroscope, or in fact any charged body, and place it in the ray of light coming through a chink into a dark and dusty room, we will see the dust motes flying from the needle as if it were a tube through which wind was blowing: or if we blow some smoke gently about the needle, the same appearance of wind driving the smoke away from the point will be seen: and a lighted candle held in front of a point on the conductor of a machine in full work, is strongly blown away from it. In whatever way the experiment is tried, it is easy to see that there is certainly a wind.

There is a scientific toy that shows this action of the "electric" wind very prettily. It is called the electric whirl, and is made of six or eight light wire spokes, pivoted on an upright conducting wire, and with all the spokes pointed, and similarly bent at right angles near their ends in the plane of their rotation. They revolve in the opposite direction to that in which their ends point.

The following are some extracts giving the opinions of the several writers regarding this wind.

"The electric charge produces a wind, and the electric wind produces a charge."

"Electricity itself flows away through the point."

"When electricity of a high potential discharges itself on a pointed conductor by accumulating there with so great density as to electrify the neighbouring particles of air, these particles, then flying by repulsion, convey away part of the discharge with them: such discharges are best seen in air or gases exhausted by the air pump."

"The electric density at a point is very great, and the particles of dust and moisture are repelled and bear away with them the neighbouring air."

Something is happening on the surface of the electrified body. There is a strain acting on the molecules of its condensed air coat which gives them a tendency to electrolysis.

Upon the body of the conductor the cohesion of its mass holds down the molecules of the air coat and resists the electrolytic action, but at the needle point there can be but little attraction of cohesion towards the metal to interfere with the electrolytic action: and at the point it is therefore more vigorous, and molecules are set free: and the molecules that are set free by the point expand sixteen hundred times in changing from liquid to gas, and so make a wind from the point, and the wind is continuous because other molecules of condensed air are continually drawn away from the body and towards the point. It is impossible to condense the explanation into an anagram, as one of the writers above quoted has tried to do, but is there need of more than is here given, or may we say "rem acu"?

There is no difference in the electric strain, or density, as it is called, on any part of a conductor, but only a difference in cohesive attraction of the material of the conductor due to its shape: and there is no electricity in the electric wind of itself, because the electromotive force that caused it was expended on the work of separating the molecules: but the wind draws the dust of the air into contact with the conductor, when each dust mote receives a charge and flies away in the wind with it to get rid of it elsewhere. The action on the conductor, produced by these dust motes, no doubt greatly encourages the electrolytic movement, so that the dustier the air the brisker should be the wind.

If the electric whirl, which was mentioned on the previous page, "be enclosed in a well insulating glass case, the rotation soon ceases, because, in these circumstances, the enclosed air quickly attains a state of permanent electrification." Bodies are said to be electrified when the molecules of their liquid air coverings are put under an electrolytic strain, and without such covering they cannot carry electricity, therefore as the molecules of air cannot be in a condition to have electrolytic coverings air cannot be

electrified. The cause of the stopping of the whirl is twofold: the restriction of the expansion to gas of the air coat molecules, and the loss of the stimulating dust, all of which has become attached to the sides or fallen to the bottom of the case. Relief of pressure increases the wind action and increase of pressure lessens it: lacking the dust the discharge and the movement cease, as may be proved by filling the case alternately with pure dry air and with air from the room. With the room air the motion is renewed, with the clean air there is no renewal of motion.

There is no electricity given to the expanding gas molecules, nor to the air that they carry with them, and it is not to them that the wind owes its power of giving a charge to any object that it strikes against, but only to the convection done by the impurities carried in the air which take their charges from the electrified body: that is, that take on a strain in their coatings which they get rid of elsewhere as soon as they can. The wind is a true wind caused by the successive expansion of the liquid gas molecules to gas, but it is not an electric wind as it has no electricity in itself, but only on the motes that it carries with it.

* * * * *

When the amount of electricity on the body is increased, the discharge becomes visible in addition to causing a wind, and what is called a glow discharge will then come from the point and will extend from it a little way into the air.

The glow is due to the action of the electric current in causing the combination of molecules of condensed air from the conductor amongst themselves, and of these with molecules from the metal of the conductor: the air gas and metallic gas molecules are driven to the end of the needle by the current, and losing cohesion to the point through its want of mass, they fly away as gas and some of them combine chemically. The glow is therefore always coloured

by the vapour of the metal of the conductor. As these molecules are few in number and are in the double act of expansion to gas and contraction through conjunction, they can give but a pale light from their contraction, and are cold on account of their expansion. The expansion of molecules always requires heat, and their contraction always produces it, but in this case the heat required is more than the heat given, so all the æther vibrations produced by the contraction are used up in the expansion from liquid to gas (except some few light vibrations which are of no use for producing expansion) and the glow discharge is cold because it wants more heat than has been given to it. This is a point to be particularly noticed, because spark discharges are commonly accompanied by heat.

"When the positive and negative glow discharges come from fine points, there is a glow on each, and if the points are in air, there is hardly any difference between them: but if the discharges are from rounded terminals, the negative glow is quite poor and small compared with the positive."

"If an earthed point be brought near a large positively charged ball, a star forms on the point and becomes brighter the nearer it is brought, but otherwise does not change until it almost touches the ball." The discharge from this point is negative.

"If the ball is charged negatively, the point has at first a star, which changes to a brush, and to a spark when close." This discharge is positive and is, as one can see, very different from the negative discharge.

"The negative glow often has a dark space at the conductor, especially in rarefied gases in vacuum tubes." And from this kathode oxygen molecules appear to be discharged in vacuum tubes.

All these differences of the two glow discharges point to their being made up of materials acting differently. We

must entirely free our minds from the common idea that electricity has any heat or light of itself: all the light and all the heat in any discharge is due to chemical action on material. "The discharge through gas resembles electrolysis," and the light and heat are due to the combining of the material, just as is the case with any other light or heat that ever occurs. Now, if the difference between the positive and negative discharges in air is the action of "driving the negative electrolytically in one direction and the positive in the other," as it surely is, then for negative and positive we may substitute oxygen and nitrogen in the above sentence and say, that the difference between positive and negative discharge in air is the action of driving oxygen electrolytically in one direction and the nitrogen in the other. The glow at the positive point would therefore be a combination of oxygen with metallic surface molecules, and with nitrogen with the oxygen continually added: and the glow at the negative point would be combination of oxygen and nitrogen, with nitrogen continually added. The dark space in the vacuum tube at the kathode is a space from which the oxygen has been rejected, and is a collection of nitrogen which remains dark because it has little to combine with to produce contraction and light.

Rarefaction, for three reasons, greatly aids the production of the glow discharge. First, because the gaseous state is more easily attained by the discharged molecules; second, because the surface molecules separate more easily; and third, because electrolytic movement is made easier. Faraday, in his investigation of this subject, made some curious experiments with charged conductors in rarefied air. He charged a brass ball positively, by induction, when it was in the bell of an air pump and under an eighth of an atmosphere pressure, and it became covered with a patch of glow over an area of two inches in diameter: he next

succeeded in covering the whole ball with the glow: and with a smaller ball the glow at once covered the whole and became brighter and "stood up like a low flame half an inch or more in height." On touching the sides of the bell, this lambent flame took the shape of a ring like a crown to the ball, appeared flexible, and revolved slowly, the light being stronger opposite the finger touching the bell. The light was stronger opposite the finger owing to induction, and all the rest is explained by what rarefaction does to help the discharge, except a slow motion of revolution which he mentions: it is not clear why the bright part should go round "four or five times in a second," unless he moved his finger round the bell.

Induction is an endeavour by the two different electricities to approach and cancel one another. The St. Elmos' fire, seen occasionally on the mastheads of ships, and the various electric glow phenomena observed on the rocks, and on the heads and fingers of climbers on mountain tops, are all induced discharges of electricity from points that are too far away from the oppositely charged cloud masses to allow of a connecting spark discharge. The water on the wet masts, or on the rocks, and the moisture on the body, serve as conductors till the air is reached, when some molecular action of combination is set up which produces a glow: the electricity, having changed to this work, is lost.

* * * * *

When the electric discharge becomes stronger the glow changes to a brush, which will be part of the subject of the next chapter.

All the actions of discharge from points—the wind, the glow, and the brush—have been ascribed to the repulsion of electrified floating particles by the similarly electrified point. But the number of floating particles in the air is much too small to have any wind-raising effect, and besides,

whatever it is that repels like electrified bodies, the action is at right angles to their surfaces, and the more strongly electrified body more strongly controls the direction: so that, except in repelling a mote from the very apex of the needle point, repulsion does not appear to have much to do with these discharges in which most of the action is in the same direction as the point. Still the direction of the flight of the motes may be first started by repulsion and afterwards changed by the action of the wind.

In all the discharges of this sort that have been analyzed, there have been found combinations of oxygen with nitrogen, and the colours of the discharges denote combination of oxygen with gas molecules of the metals of the points.

DISCHARGE

CHAPTER XVII

BRUSH AND SPARK DISCHARGES

When a stronger charge of electricity is given to the conductor, the glow gives place to the brush. Brush discharges can be made from both electrodes, the positive being longer, and the negative more easily formed. The positive brush begins at the conductor as a short bright stalk, which divides into short branches, and there is a crackling sound, and a wind in the same direction as the brush. The negative brush is smaller, less bright, and generally attached to the conductor without a stalk, and more like a star.

When the brushes are examined with Wheatstone's revolving mirror, they are seen to be dotted with a succession of minute sparks. The brush is best seen when it comes from a round-ended conductor, and the same charge that will produce a glow from a point will often produce a brush from a knob.

Whatever may be the shape of the conductor, it is damaged by the brush, spark, or flame discharge, and blunt conductors suffer most: small particles of the metal, ranging from molecular size to palpable dust, are torn off, and the conductor is left rough and pitted. Each of the larger particles carries away with it a coating of condensed air, and the molecular ones become gaseous and unite with the gases of the air coating, and in flash discharges are dispersed between the electrodes and assist the air molecules in the transfer of electricity. The light of the brush is coloured by the incandescence of these metallic vapour molecules. These are the little sparks seen with the re-

volving mirror, and the glow of the brush, in which they are mixed up, is from the feebler light produced by the compounding air molecules.

The light in these, and in all cases, is from chemical combination. One or other (or both) of the gases, oxygen or nitrogen, is thrown off from the conductor mixed with metallic vapours, and these combine together, or with the air, to produce the light of the brush: its crackle is also due to this combination: and there is no electricity in the brush itself, though there may be in what it carries with it, because the electromotive force is expended in moving these gases and is thereafter lost as electricity. There is no such remainder after any action as work plus result: the work is expended and the result alone remains.

* * * * *

Whenever the excitation is strong enough a spark passes between conducting bodies. It may be of any length, from the lightning flash of several miles to the minute crackle you get from a cat's back and which you can only see indistinctly in the dark. It is a chemical combination produced by reaction from the electromotive force, or electrical potential, as it is sometimes called.

The voltaic current has little electromotive force, and Mr. DelaRue, with eleven thousand cells in battery, could only obtain a spark two-thirds of an inch long, and with this sort of electricity, to produce a spark a mile long, would require, it has been calculated, a thousand million Daniell's cells: while with a single statical machine turned by a small boy, a spark of a foot long can be obtained, because of the greater force developed. It is evident, then, that the production of the spark and the distance it can cross, both depend, other things being unchanged, on the electromotive force. It is the electromotive force that compels the gases and vapours of the air to separate and recombine and carry

on the electric current: and unless it is strong enough to produce this electrolytic effect in the air for the whole distance between the conductors, no spark passes.

When a conductor is discharged by another conductor at a certain distance from it, the spark lasts for a very short time—one twenty-four thousandth of a second—and then in place of it we have a brush. But if we decrease the distance between the conductors, we can get a fresh spark but smaller than the first, and we can repeat this, getting less and less discharge each time, till by contact the last of the charge is freed. Apparently the strain in the condensed air covering of the charged body does not find the time allowed by the spark sufficient for complete relief.

"When a spark has passed it is easier for a second spark to follow in its track: probably the first spark produced chemical changes in its path that do not immediately pass away." It is not however the chemical changes, but the effect of the chemical changes that help on the second spark. Every spark produces chemical changes giving light and heat; an increase of heat makes chemical change easier: so the next spark passes more easily along the heated track: not because of any compounded material left by the first flash, but because of the less resistance to chemical action making the way easier. Some photographs of lightning flashes have lately been published by "Knowledge," and one of them shows what looks like a ribbon of twenty or more bright threads—the storm has carried the track of the lightning across the face of the camera, and the lightning has used this one moving track for these discharges, which have been consecutive because the cloud has not had time to send all its electricity at once to the discharging point.

"Perfect vacuum is perfect insulation," because there is no material in it for chemical action, and such chemically acting material alone conducts: but it conducts better for being made more ready to act.

"An increase of pressure increases the resistance of air." Here again we see the condition of the air determining the passage of the spark. The electric force has to produce a certain condition of the molecules before they can unite and propagate the current, and pressure, by increasing their density, increases their resistance to change.

Sparks are more easily formed under relief of pressure, and "sparks are longer and straighter in hot air than in cold: and when a compound gas is heated to its point of dissociation, the discharge occurs more easily." We can easily understand this: the electromotive force that was not strong enough to affect the unprepared molecules has now so little to do that it easily makes its electrolytic way: the train of molecular conductors is more easily formed and acted on.

The length of the spark then depends firstly on its force, and secondly on the reduction of the resistance of the medium. But its brightness has much less to do with these than with the quantity of electricity in the discharge. A strong potential can force a passage for a small quantity of electricity, but its course will resemble a thread: while if there is just sufficient force to secure a passage and an ample current, the display may become a fine flame. On account of its amplitude of current the voltaic spark is always brilliant, and even under distilled water, when its electromotive force must be much reduced, it is still brilliant. But do not let us forget that the brilliance is not electrical, but depends on the chemical combination of oxygen with some other material: it depends in fact on combustion. "If a powerful current is passed through two iron bars touching in water, the kathode becomes covered with a luminous layer and becomes red hot": the iron is combining with the oxygen of the water, and the combustion produces light and heat.

"Discharges in gases have specific character according

to the gas. They are obtained in nitrogen more easily than in any other gas." This is odd, as we do not know of any combination of nitrogen with itself resembling ozone, and experiments should be made to find out whether argon, or any of that class of gases, is produced. If no oxygen or metallic vapour is present, then some composition of the gas itself must take place, otherwise there could be no conduction.

"If the spark passes in dry hydrogen, nitrogen, or in vacuo, there is no difference between the heat and light produced whether the metals are oxidizable or not or which is used for anode or kathode." The vacuum here spoken of is rarefied gas: if it were perfect there could be no gas and consequently no discharge. The rarefied hydrogen, nitrogen, and air conduct the spark by electrolysis in some way, and that they do so must depend on one or more of three methods: either the gases combine in themselves: or the gases combine with the metallic vapour of the electrodes; or the apparatus was not cleaned of its coating of condensed air and this supplies the electrolyte. In some way the electricity is provided with an electrolytic bridge, without which its passage is impossible. From what is said, in the above quotation, about metals, one might be led to suppose that the electrodes are not acted on by the current, but in general in these cases the light is coloured in such a way as to show that there is vapour of their metals mixed with the gas. In the case of hydrogen a hydride is formed, and perhaps the chemists will tell us whether nitrogen can act on metallic vapours without oxygen.

"Iron in air or oxygen gives a brilliant arc, but in hydrogen or a vacuum, with the same power, only a feeble spark at the moment of disruption. Mercury in like case gives a spark more nearly approaching what it gives in air." The iron, when it had to depend on its condensed

air covering for effecting a passage for the current, could make but a feeble and momentary spark from want of material, as it is not a dense metal and can attract but a thin coating of air: while the mercury, which is one of the heaviest of metals, nearly four times as dense as iron, must have a thick covering and would besides help with its vapour which is easily produced.

"The more near to points in shape the contiguous ends of the conductors are, the more easily is the spark discharged." The molecules at the point are cast loose as vapour by loss of cohesion, and assist the conduction through the air, and the potential is increased by finding less resistance. Thus in two ways a point helps the electromotive force in breaking down the resistance of the air, while neither of these actions can occur to any similar extent on a rounded conductor, on which the condensed air is pretty evenly tied down by cohesion.

"Actinic waves falling on a point assist it to discharge." They make the molecules of air and other materials at the point more ready for chemical change, and so causing them to offer less resistance, the electromotive force finds less to do.

"If a wire be attached to a charged body, and the other end of it put in a flame, the body is discharged and cannot be charged so long as the end of the wire is in the flame." The moment that anything that can conduct and is uncharged touches a charged body, it shares the charge if insulated, and if not insulated carries it away. The condensed air coat on the charged body is under a strain, and relieves itself, on contact with another uncharged insulated body, by transferring to its air coat a part of its strain, and when the wire, in this case, which has taken on the electric strain is put in the flame, its electricity finds there many molecules in the act of combination, and to them it can pass on its action, and by so doing drain the charge from the body.

A point that we must constantly keep in mind is, that chemical combination is essential to the production and conduction of electricity and not decomposition or dissociation. Decomposition may precede combination, but combination, or some movement equivalent to it, is the action that produces and carries on the electromotive force. It is often stated that the air, or a wire, or some other thing, acts as a conductor, with the inference that the electricity uses them as though they were tubes quite inactive and quite unaffected by the current. This is a deduction from a confusion of ideas and quite wrong. Electricity must in every case have a chemically active conductor, whether it be fluid, or gas, or condensed air on a solid, and even the surface itself of a metallic conductor is usually chemically acted on, and without chemical action there is no current. So if ever we are puzzled for a moment by some specious explanation, let us think of this and use it as a touchstone, and if it gives no confirmation, then we may reject the idea.

DISCHARGE

CHAPTER XVIII

CHEMICAL ACTION OF DISCHARGE

"THE spark discharge, when more than half an inch in length, is a main unbroken line of light between the conductors, with forked branches which terminate in the air between. The main line follows the main stream of particles and the branches exhaust their energy in the more thinly scattered particles at the sides and so disappear." From this one would suppose that the conduction of the spark between the conductors was entirely due to the bits of metal torn off from their ends: but beyond helping the air somewhat these particles do no good: rather they do harm, for it is through them that the branches break away and electricity is wasted. They are small charged bodies and some of the electricity is enticed away to follow lines of these wanderers, and after it has caught them, the branch can only waste its force in the air and disappear in change to heat. The main line uses the air as its principal electrolyte, and always, when there is a disruptive discharge, the fact that the air is acted on is made sensibly plain by the smell of ozone and nitrogen compounds, the taint that these give having long been known as the electric smell. The electromotive force acts to combine the mineral vapour molecules and to use them also, for the spark is tinged with the colours of their incandescence; but the main carrier is the air, and the measure of the volume of its oxygen absorbed is the same as would be liberated by the current in an electrolyte in the circuit.

The branches always point to the negative electrode,

and this is one of a few apparently unexplainawayable circumstances that seem to prove that there is one current only, and that it passes from the positive to the negative pole—from the anode to the kathode. It is not as if the branches took a devious way but eventually reached the whole way across: they start towards the kathode and wandering from the way are lost without having any sort of connection with it. There can have been only positive electricity in these branches, and no reverse current possible, nor any chance of negative electrical action in them.

The positive end of the spark is both brighter and hotter than the negative, and also it has been found that the consumption of metal is almost entirely at the anode, and that the length and brilliancy of a spark, in an oxidating medium, depends on the oxidability of the anode, while the kathode may be made of platinum, or carbon, or any unchangeable metal, without dulling the spark. In fact the oxygen of the air in contact with the anode assisted by its air coating and metallic vapours forms the starting-point of the track of the spark.

"With the kathode cooled and the anode heated no current passes." By cooling the kathode the condensed air on it is certainly made to attach itself more strongly and so to resist action, but it is by the heating of the anode, which dissipates the air attached to it, that the action is stopped. It is almost equivalent to putting the anode in a vacuum: nothing can come into touch with it: no chemical change can occur on its surface, so no current can pass from it.

"The negative discharge in air is seven or eight times more frequent than the positive, but with far less electric force. The negative discharges with a lower tension." The oxygen is combining with the anode to produce the electromotive force, and there all the resistance originates:

while at the kathode there is no action nor resistance but what is due to the slight cohesion of the liquid gases to the metal.

Electric discharges in tubes are merely ordinary discharges complicated by using particular gases or vapours, particular electrodes, and much relief of air pressure, and magnetism is occasionally thrown in to increase the complexity. The tubes are called vacuum tubes, but should be called rarefied tubes as a vacuum is unattainable. In a true vacuum no electric phenomena would be seen as no current could pass. Some of the colour effects in Geissler's tubes are remarkably pretty, and they teach us that some of the metallic molecules have been forced by the electricity to unite as vapour with the gas in the tube, giving out by their contraction in doing so the vibrations that produce the characteristic colours of their rays. "In a vacuum tube the colour of the light differs according to the metal of the electrodes, proving that the separated molecules are gaseous." The colour also depends on the gases used. "The conduction in gas is electrolytic," and it is this combination that allows of conduction through the tubes and that produces the light and colours.

But this is not the opinion of all scientists: here is another explanation. "The luminosity of rarefied tubes is due to dissociation and impact of molecules in addition to oscillation of electric waves."

Dissociation is separation, and separation gives relief from cohesion, with expansion and cold. Impact might produce light if it forced the molecules to combine, because they would then contract and produce æther vibrations in doing so; but evidently this is not the meaning as separation is spoken of. And the electromotive force has no light of itself, because its waves—even though they can affect the æther—are very much too large to produce light vibrations in it.

What may be called electric waves, that is the æther vibrations of the electromotive force, in their encounter with material can only act mechanically on the molecules: their peculiar action, so far as we have seen, is to electrolytically drive them apart: and if the molecules respond very vigorously in recombination, they produce light or higher vibrations: if with less vigour heat: and if with less vigour still, they reproduce electric waves. The luminosity of the tube is a modification of the spark in air: the difference is that in the tube the molecules are much more expanded, and their contraction in compounding is consequently so much more violent that they can only produce for the most part those higher vibrations that are light-producing or actinic: and because they are few in number, their united light is feeble.

"The discharge in the Torricellian vacuum has a feeble light which is increased by heat." If a six-foot glass tube, of the gauge of a barometer tube, be bent in the middle so as to form a long loop with parallel sides joined by a semicircular head: and if it be filled with mercury and then inverted with the two ends in cups of mercury: the bent part will contain a Torricellian vacuum: and if a discharge is sent through it from wires dipping into the cups, the vacuous space will give a white glow. This light is from the vapour of mercury and a small quantity of air drawn from the surface of the glass which are acted on electrolytically by the current. If the bend is warmed the brightness of the glow increases, because both the amount of mercury vapour is increased and also the amount of air liberated by the glass.

Many curious effects are produced by varying the action and the shape of vacuum tubes, most of which would require a separate explanation with much repetition that would tell us nothing that we have not heard already, so we will only notice two effects. One of these is the

production of striæ. With a certain amount of exhaustion the luminosity is divided by dull bands throughout nearly the whole length of the tube even when it is several feet long: the bands flicker about or pass slowly to the kathode, and they are almost perfect examples of stationary waves, the length of the wave being the distance between two bands. The negative discharges occur oftener than the positive, and their comparative rate is apparently controllable by the relief of pressure, and when a particular limit is reached, the negative by giving two discharges to one of the positive, produces an alternate combination and interference between the waves of the electrolytic current in the tube: the combination produces the bright bands where the electromotive force is more active and where much of it is wasted changed to light and heat: the darker bands being the interferences where all the force that is left is used in causing electrolytic action with which to carry on the current. Examined by Wheatstone's revolving mirror the striæ show a succession of minute sparks which are due to the violent recombination of the molecules.

The other effect can be seen in another form of these tubes, which is pear-shaped. The anode is placed at one side, and the kathode, which is a slightly concave disc, at the small end. With a strong current and very high exhaustion the oxygen molecules appear to be shot, from the surface of the kathode to the broad end of the tube, where, on striking the glass, they produce phosphorescent light. In some of this sort of tube there is a little Maltese cross of mica which intercepts the action and, by shielding the glass, produces on it an apparent shadow. And sometimes there is a little paddle wheel to show by its movements the force of projection of the molecules.

When more moderate exhaustion is used, and with a saucer-shaped kathode, the discharge of oxygen in these

tubes can be concentrated at a point and will produce enough heat to make a platinum wire placed there red hot.

We must bear in mind that the current flows through both wires, and that all electrical movement is effected by electrolysis: and considering these facts the explanation of the above phenomena will not be found so simple as the effects would lead one to suppose.

The oxygen molecules, being material, have certainly acquired inertia of motion, but there is nothing to show that they have traversed the distance between the kathode and the glass as independent projectiles. They have moved in the usual electrolytic way, and being few in number, from the high exhaustion, they have moved comparatively quickly, perhaps as much as a quarter of an inch in a second. Their inertia, and the particular shape of the kathode, have caused them to move in a parallel stream at right angles to the face of the kathode. When these molecules reach the glass, they condense to liquid upon it, but immediately become gaseous again, as they are in excess of the condensed coating that the glass can retain: and they then pursue their electrolytic way towards the anode.

Because in these tubes there is this negative oxygen discharge and no apparent equivalent nitrogen bombardment on the kathode, some physicists say that there is negative electricity only, and no positive. But because it is not perceptible is no proof that there is no movement in the nitrogen. The nitrogen molecules are four times as numerous as the oxygen and are lighter, so they must receive much less impetus: and more recent experiment has shown that there is a faint light made by the condensation of the nitrogen molecules on the kathode disc, and when a hole is cut in the middle of the disc, it is seen that the nitrogen molecules stream a little way behind it owing

to their inertia. The feebler light they give is due to their feebler action and lack of material to combine with.

In the body of the tube there is no movement perceptible either way, but only at the terminations of the stream of molecules, and as the movement of the oxygen is deduced from the light given off on the glass, so also we must conclude that the nitrogen moves because it also gives light though more feebly for the reasons given—and both gases move electrolytically.

In every case where light and heat are produced they come from contraction of molecules, but the contraction may come about in various ways. When a current meets with resistance in passing over a conductor, or through air, or an electrolyte, we find that the electricity and the contraction must be nearly related. The electricity acts on the molecules and forces them to assume a position in which their natural power of cohesion is able to recombine them, and the contraction due to this combination produces the light and heat. The light is brilliant, but in the case of the spark in air the heat does not appear to be very great: an inflammable substance like ether may be set alight by it, but it will not fire gunpowder, which is blown about by the spark. Evidently there must be many light vibrations in the spark and few vibrations of heat. "The spark from a Leyden jar will scatter gunpowder without firing it unless it is passed through a wet thread or other resistance." The undamped force has so violent an action on the conducting molecules that their recovery is also violent, and they only produce those short vibrations in the æther which occasion light but are devoid of heat-producing power: while with the damping string included in the circuit the force is reduced, and some of the reproduced vibrations are then those longer ones that cause heat.

The discharge of frictional electricity is always confined

to as narrow a line as possible, for there is but little current, and to spread it into a thick column of air would exhaust the electromotive force unnecessarily. This electricity finds its way by acting on as small a quantity of material as it possibly can, and it goes far along a narrow track. With voltaic electricity broad flames can be produced, for there is abundance of current, but they do not carry far because the electromotive force is wanting.

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The noise made by the discharge is the wave of disturbance of the air by the expansion that accompanies the discharge.

There is a scientific toy that shows this expansion of air very well. It is a small glass mortar, shaped like the military cannon of that name, and in it are two wires ending in small knobs. When a spark is passed between the knobs, a ball, resting on the mouth of the mortar, is shot up by the expansion of the air. We say here by expansion of the air, but we need not take it for granted that the molecules of the air are expanded in the same manner as they are by heat, or through any heat of the spark. Heat can expand a compound molecule without in any way dissociating its chemical components, but the current can only act by dissociating the components with every wave. Now the components of the compound molecule are bound together and contracted by their mutual cohesion, and when separated they every one of them expand, and it is this expansion that drives the ball off the mortar. In expanding they require heat, and in contracting again give up as much, so there is neither cold nor heat displayed.

This expansion of material by electrolytic action may be shown in other ways. For instance, the bursting of a glass tube filled with water by a discharge sent through it, and if a card is put between two points and a spark is

passed, a hole, with ragged edges that project on both sides, is made in the card by the expansion of the air in the track of the spark through the card. Glass may also be perforated in the same way, but the discharge must be a strong one. The glass in the electric track is reduced to powder, because the composition of its molecules has been broken up and the cohesive force of the separated atoms is not sufficient to bind them together again. This experiment sometimes fails from the electricity passing round the edge of the glass plate, and if it has once done so, it is useless to try again with the same piece of glass, as the current will always follow the same line that it first took: it has had some effect on the surface molecules that changes their relation to the condensed air coating.

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From what we have learnt in these chapters, it appears that the electricity on electrodes sets up a strain in the medium between them, and the spark passes if the electromotive force is strong enough to complete electrolytic movement throughout the whole of the intervening distance. And the only difference between a discharge in gas and conduction in a voltaic cell is, that the first needs more electromotive force, is noisier, and is generally discontinuous: both are electrolytic.

INFLUENCE

CHAPTER XIX

ACTION OF INFLUENCE

Induction was the name originally used, and still often used, for the action we are about to study, but it has since been particularly applied to the induction of currents, so, to avoid confusion, we will use the word influence which is being generally substituted for it, and which is understood to mean the induction or production of charges by charges. This then is influence. If we give an insulated body a charge of electricity, it will electrify all the near-at-hand surrounding bodies to a more or less appreciable degree.

Influence does not in its action resemble heat, excepting that its effect diminishes quickly with distance. In heat there is exchange between differently heated bodies with gradual loss and gain: here no part of the original charge *appears* to be dissipated by the influence which produces change elsewhere: and the change in the influenced bodies is instantaneous. This is unnatural and contrary to our ideas of work. If the charged body acting through the intervening medium can disturb other separate bodies, whether by rods of force, or ejected electrons, or radiant vibrations, or in any other way, there should be something working on the charged conductor to produce this transfer of force, and there should be a continued relative loss and gain of power. No satisfactory explanation and no examination of this part of the subject seems to have been undertaken as yet, though theories have been conceived in plenty:

and yet the discovery of an action on the receiving body having been made, the description of the method of that action is surely the first point we ought to know when studying influence.

If an insulated conductor is charged with electricity in any way, it induces a charge of the opposite electricity in all neighbouring uninsulated bodies. If the charge given to the conductor is positive, the charges produced by its influence are negative, and *vice versa*. And these charges disappear when the bodies are removed beyond the range of the influence.

If the influenced body is an insulated body, unlike electricity accumulates on the side of it nearer the charged conductor, and the like electricity is repelled away as far as it can go. If now we put this influenced body in connection with the earth by touching it for a moment with a finger: all its like electricity leaves it and it becomes charged with electricity unlike that on the conductor. We can now take this insulated body with its charge of electricity to a distant part of the room, and transfer its charge to a Leyden jar, or dispose of it in any other way, and then replacing it near the conductor, and touching it again with a finger, we have it recharged, and we can do this as often as we wish without apparently lessening the original charge on the influencing conductor.

Two insulated charged bodies placed near together react upon each other. If they are similarly charged, their charges are repelled and accumulate in greater density on their further sides: and if they are charged with unlike electricities, these accumulate on their adjacent sides: and in both cases the nearer they are the stronger the interaction. With contact dissimilar charges neutralize one another, and the action ceases if the quantities have been exactly equal: if any excess remains, this remainder is spread over both bodies, and when they are separated

they again influence one another, though of course in an opposite manner and in a lesser degree.

The action is similar if one of the insulated bodies is uncharged, and is put in contact with the charged conductor. The dissimilar electricity, accumulated towards the point of contact, is neutralized by a part of the charge, and the two bodies are charged with similar electricity equal in amount to the original influencing charge: there has been no loss or gain.

If a charged body is introduced into a hollow conductor, it induces an opposite and equal charge on the inside of the conductor, and an equal charge similar to its own outside. If for instance the influencing charge is positive, it induces equal negative inside and equal positive outside. If now the introduced body is put in contact with the conductor, its positive and the inner influenced negative charges cancel, and the conductor is left with a positive charge outside, exactly equal to what would have been given to it by immediate contact inside or outside.

If two bodies with dissimilar charges of equal intensity are introduced together, but not touching one another, into a hollow conductor, they produce no effect as their effects cancel one another.

When the surfaces of insulated bodies which are under influence are tested by means of the proof plane, it is found that they have a coating of electricity which is denser towards extremities and projections and which is positive or negative according to the position of the part in relation to the charged conductor, and to the sort of influencing charge on the conductor; and the coating of the electricity on the charged conductor has a similarly arranged distribution. If we were to draw the outline of this electric coating on such a conductor as is commonly used for these experiments, and which has a short sausage shape, we should find that this outline resembled a light dumb-bell:

all projections have an accumulation and points draw the electricity towards them and discharge it as in other cases. The coating of electricity on the influenced body entirely disappears on its removal to a distance from the charged conductor. There has been a separation produced on the surface of the influenced body by the action of the influence: and the separated matters resume their ordinary admixture, or conjunction, or composition, or whatever it was that was disturbed and driven apart by the influence.

"The passing of a charged rod over an electroscope causes the waves to flap to and fro but does not charge the electroscope—but if a metal point is added to the bulb, the rod passed at twice the distance will charge the electroscope." What happens when the electroscope is thus charged is not that the electricity from the rod is poured into the electroscope through the point, for the rod apparently loses none of its charge, but that by the influence of the charge of the rod there has been a separation in the electroscope; the unlike electricity has been drawn by the influence towards the point which has been unable to retain it, and it has, as we suppose, been dissipated upon the dust and vapour of the air and in producing a wind, while the like electricity appertaining to the electroscope has remained to charge it. The same result happens if the glass rod is put in contact with the point: the electroscope in both instances is charged with positive electricity: but the influenced charge is produced by taking something away, and the conduction charge by adding something. This is rather puzzling.

We must not, if we wish to charge an electroscope by influence, bring the charged rod too close to the instrument, for the rod would certainly empty itself by discharge into the bulb or point, and the electroscope would then have a positive charge very much stronger than the charge it could have got by influence. A well-electrified rod will

show all the influencing effect if held nine inches or a foot from the electrometer, which is a delicate instrument likely to be damaged by rough shocks.

There are some electrical machines, called influence machines, which have some outside resemblance to the plate frictional machines, and which are made to work on this principle of influence. They require a small charge, such as may be got by rubbing a glass rod, to start them, but once in full action they are more powerful than the static machine, and much more reliable. You have no doubt seen descriptions of these machines in elementary works on electricity.

By the influence of a charged body both electricities are generated in equal quantities, that is to say that the positive and negative electricities separated on an insulated body, the one attracted towards the charged conductor, and the other repelled from it, will be equal in amount. The amount produced however will in no case be equal to the influencing charge. For instance, half a dozen equal-sized bodies surrounding at equal distances a positively charged globe, could not each of them have more than a sixth part of a negative charge equal to the positive charge on the globe, and would in fact have much less, for, like all radiating influences, distance decreases the effect in proportion to the square of the distance. Increase of strength only increases the induced charge in equal ratio. So the repulsion between two bodies will be the product of their two electric charges divided by the square of the distance between their centres: or $\frac{e \times e'}{d^2}$. And this also gives the measure of their attraction if they are differently charged.

Influence induced by powerful charges is reinforced in enclosed spaces by reflection from the enclosing walls. "The alternating charge is distributed upon the opposite

coatings of the walls, the air between taking the place of the glass in a Leyden jar. Electric waves fill the air giving to-and-fro motion to it." The last sentence is wrong. The glass in a Leyden jar has no to-and-fro motion and neither has the air from the influence waves. So long as the electromotive force on the insulated charged conductor is acting, so long will æther waves be produced which will no doubt pass to and fro in the room by reflection from the walls: and they will necessarily act on everything in the room, and in so acting will be destroyed, or we should say, converted to other work by producing action on the walls or other bodies they encounter. But it is neither the glass of the Leyden jar nor the air of the room that is the medium of the induction rays, but the æther that traverses the air or glass. The stress of the electromotive force sets up an electrochemical motion in the liquid condensed air coat of the charged conductor or surface of the Leyden jar: and this motion produces radiant induction waves in the æther in the air of the room or in the glass of the jar: and these æther waves set up electrochemical motion in the condensed air coatings that they encounter, and this produced electrical motion on the surfaces is in the direction of the rays of influence, that is away from the influencing body, but of the same electrical denomination, and the reverse electricity is left to accumulate on the nearer sides of the influenced bodies.

The charge on a conductor produces in this way opposite charges on all the objects in its neighbourhood: so when the conductor is discharged, all the objects that have received counter charges by its influence are also discharged. This relief of tension is what is called return shock. It can never be equal in strength to the influencing charge, nor can it act far, but in lightning stroke it is often felt a hundred yards or more from the point where

the lightning strikes, though even when very much nearer it is seldom fatal.

Influence does not act to any great distance. A cloud will induce electricity in the earth a mile below it, and a conductor the size of one's head, charged and placed in a small room, will induce a small amount of electricity on any object in the room, but a furlong away from the land covered by the cloud, or on the walls of a large room there would be no appreciable effect. It is evident from this that influence is not of the same nature as the radiant Marconi wave which travels to very great distances. The two—Marconi and influence waves—are constantly mixed up in explanations of electrical experiments and actions, and as no doubt there are many occasions when both sorts of waves are produced at once, we must analyze descriptions of results very carefully that we may avoid being led astray.

INFLUENCE

CHAPTER XX

INFLUENCE IS AN ÆTHER WAVE

INFLUENCE waves are produced by local action. Of this there cannot possibly be any doubt, for no movement can originate itself, though present-day theorists try to make out the contrary as regards electricity.

When a body is charged and owing to insulation the electromotive force cannot escape, influence vibrations are produced: and we also find that they are produced when a current is sent along a conducting wire: and as they are produced by the electrolytic movement on the wire, we may judge that they must also be produced by some electrolytic movement on the insulated body.

No mere strain could produce vibrations in the surrounding æther: they could only come from completed movement: so we are compelled to believe that the molecules of the surface under strain on the insulated body do complete some slow electrolytic movement from which the influence waves result.

A glass surface such as the inside of a Leyden jar can be charged where it is covered with foil, and the electrochemical action so set up produces æther waves that radiate in every direction. Those that radiate inside the jar are cancelled: those passing through the glass influence a similar electrochemical action on the outer surface, the like part of the charge escaping to the earth and the unlike remaining. The glass between is sometimes pierced if too thin: and this has been ascribed to disruptive action between the charge and the induced electricity on the

outside of the jar: or to the violence of the vibrations set up in the glass through its being the intermedium between the inside and outside charges. Such ideas, though they have a shade of truth in them, lead us quite away from the real cause of rupture, which is, that the electromotive force has had sufficient energy to force the glass at its weakest point into electrochemical action: the glass has been forced to become electrolytic: its molecules have been dissociated, and, if they could, would have recombined in just the same manner as any other electrolyte. Had the glass been a better electrolyte the hole would have been repaired with slight loss.

It is also said that "the charge strains the surface," with the idea more or less definitely expressed that the strain is electricity. The strain is resistance to electricity: the molecular resistance of the glass against decomposition by the dissociating stress of the electromotive force: and the resistance is not of the surface, but of the substance of the glass.

The thinner the glass the greater the capacity of the Leyden jar, because the energy of the influence increases inversely as the square of the thickness, but the thinner the glass the more care must be taken in discharging, for thin jars are often spoilt by careless discharge. If the jar is discharged by a wire touching the knob and the outside coating at one point, the jar may be broken through there because the electromotive force must accumulate at that point, even though it may be but for a twenty-four thousandth part of a second, and it causes an accumulation on the other side at the same point, and the two electromotive forces of these two electrodes may find that they have sufficient accumulated power to overcome the cohesion of the components of the molecules of the glass, and take this shorter route. It is to prevent this that the jars are sometimes filled with crumpled foil, or have

other devices by which the electricity is drawn from many points of the inside at once, and they would be made safer still if some arrangement, acting in the same way, were applied outside. But the jars would not be made any more powerful by these means, for they could not take a larger charge since it is not the foil that receives the charge, but the surface of the glass.

"A slab of glass three inches thick has been pierced by the discharge of a powerful induction coil. A layer of oil resists being pierced as much as a layer of air five or six times as thick would be. Toughened glass is less easily pierced." It is the molecular resistance of the substance against electrolysis that is the "strain," and not electricity.

When we charge a Leyden jar, we charge the glass, not the foil. Experimenting to find out where the electrification of the jar lay, Benjamin Franklin made a jar with movable coatings, and on removing them from the glass after the jar had been charged no electricity was to be found on either of the coatings: but on putting them back again on the glass, the arrangement was found to be charged as before. The electricity had been left on the surface of the glass.

When we charge a Leyden jar, we hold it with our hand touching the outer coating: the outside must be in connection with the earth, for no charge can be given to an insulated jar: we present the knob to the prime conductor of an electrical machine, keeping the two about half an inch apart, and sparks pass for some time: when the sparks have ceased the jar is charged, and we can keep the charge stored, though not for very long.

A very much larger charge can be given to such a jar than can be given to an ordinary conductor, because with every addition to the surface we are charging, an equal addition of unlike electricity is made to the other surface by the electrolytic action on the conductor from the earth, and the two electricities have a mutual influence that

holds them bound to the two surfaces. The action on either surface is to produce æther influence waves which give the glass molecules between them an inclination to move their components electrolytically towards the surfaces, and it is the cohesion of the glass that resists the completion of this movement and the conduction of the electricity. The forces therefore that bind the two electricities must reside in the condensed air coatings of the two surfaces. And we find that they act so strongly that we may touch either surface, and remove no electricity from it so long as we do not touch both surfaces at once—which we should be very careful not to do as it is dangerous with a large jar, for you give your body as an active electrolytic path by which the electricities escape and cancel one another.

Influence acts through æther, air, glass, in fact through any substance unless it is a conductor, or to put it concisely, the worse conductor the better inductor. Charged bodies repel or attract more through a vacuum than anywhere else: more through glass than ebonite: more through ebonite than air.

Many experiments have been made with screens set up between electrified bodies, which, except in the comparison of the action of various conducting substances, are not of much use, for influence can get round a screen most easily. M. le Bon found that it was extremely difficult to exclude influence and other electrically produced æther waves even with metal screens, because they made their way through the narrowest crevices. So the placing of a plate of glass in plain air between two excited conductors does not teach us much.

However some very pleasing and convincing experiments, which were invented by Vanderfliet, can be made with wire gauze as a screen, and the apparatus can be easily made. All that is wanted is a piece of wire gauze eighteen inches by six, with three pieces of strong wire twelve

inches long, fastened to it at the middle and ends, so as to project all of them six inches from one side: fasten the free end of the middle wire into a piece of glass tube on a wooden foot, and encase the other end ones in glass tubes which will serve as insulating handles: attach a number of slips of paper, two inches long, by loops of cotton thread through their upper ends, along the middle of the gauze on each side, and the machine is complete.

Electrify a glass rod and scrape its whole length upon the top of the wire gauze so as to transfer all its electricity to the wire, and the paper slips will stand out on both sides of the gauze: bend the gauze into a ring and the inner slips fall, while the outer slips stand out further: reverse the bend of the ring, turning it inside out, and the action of the papers is reversed: form the gauze into the shape of the letter S, and the papers stand out from the bulged sides and droop on the inner sides of the bends. Now straighten out the gauze, and having electrified a conductor with the glass rod, bring it near one side of the gauze: all the near paper slips are flattened against the wire, and those on the further side stand out: and with a negatively electrified conductor, the slips point towards it on the near side and cling to the gauze on the far side. Anyone who has seen these experiments will not fail to perceive that the electricity is something belonging to the wire, and that the influence is something acting in the medium between the charged bodies.

It is plain that influence must be an action taking place in the æther, as it acts through a vacuum as well or better than through anything else: and as the only action that can go on in æther is vibration, we may safely say that influence is an æther vibration that has nothing to do with molecules beyond that it is originated by them and reacts on them: and being a motion it is only by its effect on matter that it is sensible to us: and if it is sensible to us, that it is through the motion of molecules that it is so.

INFLUENCE

CHAPTER XXI

INFLUENCE AND INDUCTION

POSITIVE electricity is produced by the coming together of molecules: is negative electricity due to the separation of molecules? Not likely. There must be a sequence of alternate molecular action and æther vibration: an act of vibration between every two molecular actions, and here there would be no vibration between the conjunction and separation of the molecules. Negative influence is as much a vibration as positive and the separation of molecules could not produce a vibration. It is not expansion, or more extensive range of movement that produces the vibrations that cause light, heat, and electricity—though this was the old idea—it is the conjunction and contraction of molecules that produces these effective vibrations: and the influence vibrations can only be produced by the coming together of molecules.

Are positive and negative vibrations two sets, or only one set divided so that we see one part reversed? The positive drawing the acid molecule to combine with the basic: and the negative pushing the basic to combine with the acid. Meeting they would act like other waves passing through without destroying one another: both producing the same action in the molecules, and merely producing them from reverse directions.

Following up this idea, it would appear then, that the coming together of an acid and a basic molecule in a voltaic cell, or elsewhere, produces a vibration, which the mere chance of position of the zinc or other compounding

material causes to be propagated, one half through the acid molecules to the kathode as positive, and the other half through the basic molecules in the opposite direction as negative. Practically making them two electromotive forces, one, the positive driving the basic molecules before it, and the other, the negative, driving the acid molecules: and both producing the same chemical action though in contrary order: and both renewing their force with every combination of the molecules: and either of these electrochemical combinations conveyed to an insulated conductor, or passed along a connected conductor, producing waves in the æther which, acting on neighbouring bodies, influence in them electrochemical action. It seems rather haphazard. However we will consider this further on when we have reviewed all the workings of electricity: our present work is with influence only after it has been produced and is acting.

There is this great difference between influence and conduction. Conduction is only possible with palpable material, and depends on the molecules and their electrochemical action, and on the electromotive force which sets up the electrochemical action of the molecules: and it transfers the electric current, whether positive or negative, without change. While it seems that influence changes the electricity, that it depends on the æther for its transmission, and has nothing to do with electricity or material beyond this, that it is produced by them and can reproduce electricity in material. Or as Tait says: "The electrical conduction of matter is entirely different from any action the molecules may produce in æther. In the æther they are æther waves no more no less. They are a radiant energy that the molecules of matter can transform into electricity." This could not be put better or more clearly.

What we have found out concerning the action of charged bodies on their surroundings must prevent our accepting

all that is given in the following extract from another author. "The space surrounding an electrified body is electrified in proportion to the distance from the body, and through this the electricity is discharged by a flame which is a number of points. But the magnesium flame discharges negative influence only." Air is very resistant to electricity, and if it could be electrified would conduct the electricity to the surrounding bodies and produce in them similar electricity, and not an opposite charge, which is what influence does. Influence acts across a vacuum which electricity cannot do, and it is plain that it is a particular vibration of æther with which the air has nothing to do.

Conductors of any sort absorb conducted electricity or the influence vibrations for their own electrochemical use, and if a point absorbs the vibrations more freely than a knob, it is because the molecules of the condensed air on it are more easily acted on, owing to lack of cohesion to the point, than the molecules of the coating of the knob. Points, flames, wire-gratings, and any conducting material in any form, absorb the influence vibrations and are acted on by them, and as they prevent them from passing any further they appear to discharge the air of electricity, but at no time were the vibrations a part of the air.

The influence vibration if produced by positive action produces a negative action on the influenced body, and *vice versa* if the vibration has a negative origin. Hence ordinary flames, which do not act because they are points, but because they have several chemical actions going on in them, can act like any ordinary conductor and accept either positive or negative influence: but when the action of the flame is confined to a single composition, such as the oxidation of magnesium, which may be called a positive action, it can accept no negative motion such as would be given to it by positive influence, but only positive

motion. The ordinary hydrocarbon flame has at least two coatings or shells, an inner shell in which hydrocarbon gas is decomposed and its carbon constituent combined with oxygen, and an outer shell in which the hydrogen constituent is combined with oxygen to form water vapour, and between these two it has been found that there is a slight electrical action: any vibration that helped this action either positively or negatively would therefore be absorbed. But in the magnesium flame oxidation is the whole process: the oxygen molecules are driven or drawn towards the magnesium, and only those vibrations that aided this action would be accepted. The action is one of conduction in the flame and is electrolytic as in every conduction.

"If a strip of aluminium or gold leaf, cut to a point, is placed, point up, between a ball kept charged with positive electricity, and a point in connection with the earth, three inches below the ball, it will remain suspended at a certain spot motionless in space, and emit small sparks from its pointed end towards the ball." This is a very instructive experiment in which conduction and influence are both at work. The author regrets that when making a note of it, he omitted to add the inventor's name, which should have been given here, with congratulations for having discovered so excellent an example.

The negative electricity is conveyed by influence from the earthed point to the strip, and from the point of the strip by spark discharge to the ball. Being negatively electrified, the strip is repelled by influence from the earthed point and attracted to the ball: but if it goes too near the ball it receives less electricity from the point and its attraction to the ball lessens and it falls; and if it falls too near the point it gains more electricity and is more repelled from the point by influence: and as the negative electricity always travels from the more receptive base

of the strip to the less retentive point, the point does not change its direction: so the strip retains both its position and direction in space.

"If the ball is charged negatively, the strip will attach itself to the ball and will not remain in any position in space." The result in this second case would have been exactly the same as in the first case but for the greater force of the positive discharge from the earthed point. The positive discharge is so strong that it breaks down all the opposition of the influence. In the first case there were two nearly equal forces pushing against one another with a strength which decreased with the square of the distance, and which were therefore capable of having a balancing point; while in the second case, there can be no such point, because one of the forces is everywhere stronger than the other is, even at its place of origin.

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When at the beginning of this study we said that the charged conductor influenced surrounding bodies without loss to itself, we were repeating what we had been taught, and which is still taught, but which certainly has not been sufficiently thought out by the teachers. The charged conductor is losing electricity all the time, and this loss has been put down to convection from it by the air, and it is no doubt for the most part due, not to the air, but to the impurities of the air conveying it away: but it is an impossibility that motion should be produced without the expenditure of work to produce it, and a part of the loss from the conductor must therefore be due to the work of production of influence waves. It is impossible to measure the amount of the influence action on a conductor in air, but it should be easy so to arrange that a body with earth connection should be charged by influence in vacuo and then disengaged and insulated. The vacuum would

prevent conduction, and the body therefore could only lose its charge by its influence on its surroundings, and the time occupied in this loss compared with the time in air would give the amount of loss due to influence.

In trying this experiment, the body to be put in vacuo must not have its condensed air coat burnt off. But the same experiment should be tried with a body heated in a hydrogen flame and cooled in hydrogen before being placed in the tube, and the tube should be cleansed of condensed air by having a hydrogen flame driven through it. With these precautions it will be found impossible to charge the body by influence—because there is no electrolytic coating to the body.

From what we have learnt, influence is a vibration of æther produced by the molecules on the surface of charged bodies; and is due to the action of electricity on the molecules: and the action that electricity forces on the molecules of an insulated body may be called delayed electrolysis.

Also, it is plain that in every instance it is influence that puts the strain on molecules to induce them to conduct. That influence, in fact, is identical with electromotive force. That the force is named influence while it sets up a strain in an electrolyte, and electromotive force when it has produced a current. There is only this difference, that influence waves radiate in the surrounding æther, and electromotive waves, having taken a definite direction through the æther associated with molecules, retain that direction.

INDUCTION

CHAPTER XXII

THE ACTION OF INDUCTION

INDUCTION is perhaps the most interesting part of our study.

In the last chapters we examined the effect produced by influence from a charge of electricity placed upon an insulated conductor. Let us now examine the influence—or induction as it is called—in the cases where it is set up by currents in conducting wires. We shall find that it has several particulars of detail which make it advisable to separate it from influence, though the two are in reality identical.

" If two wires are close together, one carrying a current, an induced current is set up in the other." When influence acted on an insulated body, we found that a strain was set up; here where the acted-on wire is not insulated electrolytic action is produced, which sufficiently proves that the strain in the case of influence was also electrolytic, and that the charge that was produced by influence on an uninsulated body must also have been electrolytic.

" Any change in the current of a wire, any pulsation, causes instantly a similar pulsation in a neighbouring wire not connected with it." This shows us that change of strength in currents produces change of amplitude in the influence waves.

" If the primary current is increasing the induced current is opposite, if decreasing the secondary is in the same direction."

This is very significant. No form of wave that we

can think of could produce this double effect, but only stationary waves, advancing with increasing power and retracting with decreasing.

It is not by any means a gėneral consensus, but opinion appears to incline to the conclusion, that the æther waves of induction circulate round the conducting wire in widening rings or spirals, and that with positive and negative the directions of the circulation round the wire are opposite.

That the induction vibrations sent out from the wire, and radiant equally in every direction, should by some manner of interference set up stationary wave rings, does not seem at all out of the way: but it is difficult to believe that a current running along a wire can possibly make those radiant vibrations move in circles round it. We will therefore leave out this complication but adopt the idea of rings. The rings, or rather cylinders, are superposed at equal distances beyond one another, and when the current increases they widen out, and when it decreases they close in upon the conductor. If a picture were drawn upon a plane in line with the wires, a series of waves would be represented in the space between the two wires where the plane intersected the successive rings: and though, if they were spirals, this would not be correct as a whole, it would correctly show what was actual at any direct line between the wires.

Now if we suppose these rings of waves to separate more from each other and from the conducting wire when the current gets stronger, and to draw in towards this wire when it becomes weaker, we see that they pass across the other wire from two directions. Is this sufficient to produce two directions in the induced currents on that other wire? The idea seems reasonable, but requires much consideration and search for facts to confirm it.

We came to the conclusion that the only apparent reason for the flow of electricity in any direction in a circuit was

the position of the acid and basic molecules in relation to one another. This being so, if the advancing waves of induction act to induce these molecules to place themselves in a certain position, and the retiring waves bring about a reversal of the position, then we can understand the reversal of the induced currents as well as their production. This does not and must not be supposed to advocate polarity, which is the idea that the solid crystalline molecules in a piece of metal execute a somersault with each change in the direction of a current, and which is an idea not reasonably acceptable. The reversal that we refer to occurs in the liquid air on the wire, and only amounts to an inducement to molecular interchange in one direction or the other as occasioned by the changes in the direction of the æther wave forces acting upon the liquid, and therefore easily movable, molecules.

" If two coils of wire be placed near and parallel to one another, a momentary reverse current will be produced in the one coil whenever a current is sent through the other: or whenever the current is increased: or when the coils are suddenly brought nearer while the current is running in one of them. And a momentary direct current will be produced in the uncharged coil whenever the coils are suddenly separated: or when the current is diminished in strength: or when it is broken off. So long as the coils are kept still and the current steady in one of them, there will be no induced current." The same effects are produced between parallel wires but not so strongly. All these actions add eonfirmation to the idea that the induction waves of æther form stationary circles round the wire. When widening out, or when pushed nearer the acted-on wire, their movement is one of advance towards it; and the results are the same, a reverse current: when closing in, or drawn away, their movement is a retiring, and the result a direct current.

The only difficulty is to explain why the wave remains idle when not advancing or retiring, for "so long as there is no change in the current, there is no effect from induction." The induction must be a continuous production, for we cannot suppose that it is a mere temporary movement set up by changing the position of a wire, or increasing or decreasing the current in it: the induction waves must be there always while a current is passing on the wire, and the only reason for their not acting like ordinary waves must be that they are these extraordinary stationary waves, and that they are of such dimensions that the inactive wire may remain in the hollow of a wave, and that its molecules may remain unaffected so far as to produce a current, or if they did produce any different action in the molecules on the wire, it could only be on those at opposite sides of it, which could only produce a current across the wire and not along it. But if the current in the influencing wire is started, or increased, or decreased, or stopped, although the charge may pass along it with the speed of light, it begins and acts on one end of the wire before it arrives to act on the other end, and the induction waves would not be all drawn across the responding wire at the same moment, but would cross it in succession and, as it were, obliquely from one end to the other, and so cause an electrolytic action to run along that wire.

With a strong current in the influencing wire, the induced action is so strong, when the primary current is broken, that a sharp shock or discharge is produced in the influenced wire: but it is only very strong currents that can do this, because induction is really a very weak force.

"A variable current produces self-induction in the primary wire; opposing if increasing and augmenting if decreasing. To set a current in motion reaction must be overcome, once in motion it continues of itself. Self-induction is a sort of inertia." This idea of inertia is

borne out by the fact that in a vacuum tube many of the oxygen molecules continue their course regardless of the position of the anode if it does not face the kathode: and we have seen the same thing occur in air when two wires joined to complete a circuit were crossed near their ends, and the oxygen propelled beyond the crossing combined with and heated one of the ends: and we have the same action in a Leyden jar, or an oscillator, where the oscillation of the spark is due to the alternate surging surcharges of the moving molecules of the condensed air coats. Wherever we have motion and material we must have inertia. In a coil of wire, each turn has an inductive action on every other turn in the coil, and the effect is magnified according to the number of turns, and the result in a coil with many turns is so forcible that it has been found that this self-induction must be taken into account in electromagnetic machinery.

"When the electric circuit is broken, the current continues to flow across the break for a short time, producing an electric spark, and the intensity of this spark is a rough indication of the amount of kinetic energy possessed by the current."

Inertia is the only inherent property resembling force that is possessed by material, and if the inertia is that due to received motion, the material expends the inertia in reproducing the motion in some form. The motion of the electric æther wave has no inertia, being immaterial, and its motion when given to material is reproduced by the material as electric, or heat, or light, or actinic vibrations, all of which are found in the spark: and it is the inertia of the electrolytically moving material that bridges the gap and reproduces the vibrations.

This kinetic energy depends on the amount of surface brought into action by the current. In a short loop there is only enough to produce a small spark, but if the circuit

is made into a coil round a bundle of iron wires, "a spark several inches in length may be produced by suddenly breaking the circuit." It is due to the collective inertia of the molecules of the air skin on the wire, which have been moving electrolytically, and which convey their electrolytic motion to the intervening air of the gap.

Some scientists say that "the energy of the waves is stored in the medium." This is a reversion to an old idea that has been found untenable, as in the case of latent heat. There has not seemed to be any need or possibility of storing either induction, or self-induction waves, and very much reason for deciding that the medium, meaning by that term the material gases, or other substances, surrounding the wires, is not used in any way by the induction waves. The energy of induction waves does not spread beyond a few feet from the exciting wire, because their force decreases quickly with distance and is but feeble to begin with, and may possibly be all used up by the impurities in air: and no instances of air storing can be cited, nor does it seem reasonable to suppose that æther ever does any storing.

When both wires carry currents there is a double effect. "Electric currents that flow in the same direction attract each other: in opposite repel." Or as another author says: "Wires attract each other if the currents in them are going in the same direction: repel if opposite." It is convenient to speak of wires or currents attracting or repelling each other, but we must clearly understand that there is no such thing as attraction or repulsion of wires or currents. The induction vibrations produce some movement of the molecules of the air skins on the wires, and this causes an equal and opposite movement of the wire to which the moving molecules are attached: the wire appears to be attracted or repelled, but in reality is pushed

towards, or pushed away from, the other wire by the molecules on its own surface.

Induction vibrations produced by currents running the same way produce identical movements in the molecules on both wires. The currents, we will say, are moving from left to right, and the induction waves therefore expand from left to right, and their action would be to hasten the current and to cause the molecules to move diagonally towards the further sides of the wires, which would push the wires together. With counter currents the induced action of the molecules would arrest the molecular current motion, thus producing accumulation on the near sides of the wires which would push them apart. It is not the induction waves that do this pushing, but the molecular action induced by the waves. Induction waves are æther waves and have neither attraction nor repulsion such as waves of substantial material have, but they cause indirect actions of this sort.

"Similarly electrified stationary particles repel, but similarly electrified currents attract, therefore similarly electrified moving particles should attract." Maxwell's theory is, "that with their velocities equal to light, the electrostatic repulsion of electrified particles will just balance their electromagnetic attraction."

The movement of material with the speed of light is a fallacious idea. The movement of the current on copper wires has been found to be twenty-four thousand feet in a second, and that of the material molecules infinitely small.

Still, you might say, that if the vibrations pass with this speed, and if molecules acted on by waves of that velocity attract: and if when acted on by waves of double the velocity—as they would be with contrary currents—they repel; then the whole question is answered.

But how? It is no answer to a question to repeat the

words that prompted the question, though the trick is common enough. What is electricity ? you ask. Electricity, you are told, is a property of electrons. What is life ? A property of animated matter. What is shoe-leather ? A leather they make shoes of. Such shallower than ditchwater answers are often accounted as splendid discoveries, but they do not satisfy all even ordinary inquirers. If we ask why currents running with great speed attract one another, and why when running with double that speed they repel, it is no answer to say, because of their speed. And besides this, one cannot conceive why the speed, whether it be a snail's pace or a lightning's pace, can have anything to do with the business: and what we really want to know is, why do currents running in the same direction cause attraction, and in the contrary direction repulsion—or rather, why are the carrying wires variously pushed by the actions caused by the currents ?

The current running along the wires cannot push them sideways: nor can the vibrations of æther, or the æther itself, in the space between the wires, push or pull them: the whole effect of the induction wave is to set up molecular action in the air skin on the wires, and it must be the effect of this action alone that gives movement to the wires.

"Two circles of wire in which flow like currents turn their planes parallel to one another in the endeavour to embrace the greatest number of lines of induction, and are attracted. They act like magnets. With opposite currents they repel—that is endeavour to turn round so as to be in accord and embrace the lines." But it is no action of the æther waves, as waves, that moves the one wire into agreement with the other: nor are there such things as lines of force in æther, sweetly simple of conception and saving of trouble as such things would be.

If we place one of the wire circles so turned towards a

second circle that it is at right angles to it like the down-stroke of a T, then the current in one part of this first circle is towards, and in another part away from the second circle. Now it is reasonable to suppose that the induction waves from the second circle should act differently on these approaching and retiring currents of the first circle: that in meeting or overtaking the currents they should oppose or assist the currents: and that the effect of the meeting wave should push away the part of the wire carrying the advancing current, and the effect of the over-taking wave should pull away the part carrying the retreating current, and the double action being in one direction, the near side of the sideways circle would be moved away until it came to be at the same distance from the second circle as the other side, after which only ordinary induction by parallel currents would act.

"Conductor circuits in which currents are flowing, turn so as to coincide in direction of current. But a single conductor, if movable, when excited turns east and west." The single circuit turns east and west to place itself parallel to the electric current produced on the earth by the heat of the sun, and which circulates with the sun. It is a thermo-electric current quite similar to those that we have studied in our examination of thermoelectric action.

INDUCTION

CHAPTER XXIII

THE PRODUCTION OF INDUCTION

THE action that produces induction is the electrolytic movement of the molecules of the condensed air upon the surface of the producing wire, and this sends out æther waves of induction which seem to be different from the waves of influence. Those influence waves acted continually without pause or change, and any movement of the bodies employed only intensified or lessened the influence according to the decrease or increase of the distance between them. These induction waves are discontinuous, and only act in response to movements that have nothing to do with electricity, or in response to increase or decrease of current, and in both cases only during the time spent in these actions.

Influence produces an electromotive force on the influenced body, and a strain against the force. Induction produces a much stronger action, a current generally, even on an insulated body: that is an electromotive force and an electrolytic movement of the molecules of the condensed air on the responding wire. Influence waves acted as ordinary waves would do, radiating from the point of origin and passing away into space without return. The induction wave acts in such a way as can only be explained by supposing them to be those peculiar combinations of vibrations that are called stationary waves.

What then are stationary waves? If you throw two stones into a pond, they will make circular waves that

spread out from the points struck by the stones, and where the circles meet there will be formed stationary waves: you can see the circular waves pass into and reappear beyond these stationary waves, but these latter keep their position. You walk beside a brook and see the water strike against the posts of a fence pushed into the stream from both sides, and from where it strikes the posts there are two series of ripples sent out into the stream and spread like the feathers of a bird's open wing, and where these ripples meet you see a strong stationary chequer of small waves that is not carried down by the stream. You try your hand at tuning your piano—a stupid thing to do unless you are a *practical* musician—and you make a discord between two notes, and produce a series of semi-stationary beats. And Newton's rings are stationary waves of interference of light waves.

What is it that in each of these cases causes the stationary wave? Interference. The waves in the water are stationary because the waves from the points of origin interfere. The waves of sound are not of the same length and through interference make beats. And we know that there can be interference in æther waves of light. What then does this point to in induction except interfering vibrations between the two wires?

The striæ seen in some of Geissler's tubes are no doubt beautiful examples of stationary electric æther waves. The current can do little by conduction in the rarefied gases, but the mutual induction vibrations are conveyed by the æther between the nodes, and these æther waves, positive and negative, being of unequal length, on meeting interfere and form stationary waves of augmentation and cancellation: and in the augmentation they act on the small quantity of gases remaining, and by encouraging the combination of the gaseous molecules they produce light and heat: in the cancellation bands no such increase

of action occurs as the effects produced by the vibrations cancel one another.

The induction interference æther wave in air is probably much smaller than those in the tubes, but it appears wide enough to allow of a wire to rest in the cancellation part unacted upon: and the wire would be driven to that part by the action of either of the augmentation parts on either side of it.

Interference then must produce the stationary waves of induction. In Geissler's tubes they are produced because the negative influence wave is longer than the positive: the distance between two striæ showing the space in which the one series has differed one beat from the other. In what way can we account for the same effect in influence from the current on a wire? In the tube the positive and negative influences were separated, one at each end of the tube, and met: but an equal effect would have been produced had they both started from one node and gone in the same direction: and this is what occurs on the excited wire. Both currents, positive and negative, pass on the excited wire, and both send out, on the surrounding æther, series of waves, which, being different in length, interfere and produce stationary waves. There could of course be none of this interference with influence vibrations because they are produced by positive or negative charges acting alone: and this is probably the only difference between influence and induction.

There is nothing to support an aerial wave theory. And there is another point that we may say that we have arrived at, and that is, that the idea that "electric lines of force are produced by induction" is a delusion utterly incompetent to explain the effects produced by advance or retreat of wires, or even of increase or decrease of current: and that æther rods, induction lines, and tubes of force, are mere fanciful examples of *obscurum per ob-*

scurius—delusions and snares. Influence and induction, though they form the basis of electromagnetism which is occupying so much scientific attention at present, have not had the thorough investigation that they deserve, and no attempt has been made to examine their origin, or explain their action, except by these mythical polar forces, rods of force, and such-like extravagances. As one writer puts it, "Men are now more interested in the pecuniary gain that new scientific inventions may bring, than in the *science* of the inventions": and they have invented for the furtherance of their object a very elaborate nomenclature and method of measurement which includes quite puzzling mathematical formulæ interwoven with ohms, and farads, and other mystic terms, without which, as a shibboleth, the uninitiated are accounted but philosophic Midianites, and unworthy of scientific existence. Modern books are crammed with mathematical formulæ, but they are not worth much as they will prove anything one chooses to put into them.

But with this mechanical, or with the commercial side of the question we have no desire to meddle: our aim is the elucidation of those points that have been neglected, and is a mere search for knowledge and not a yearning for lucre.

Judging from what is published, it strikes one that the mathematical forms employed by the invention seekers are not always based on correct theories, as the following will show.

Electric influence = inductive power, and "its effect in dry air is taken as the standard of comparison at 1. Gases have nearly the same power as air. The property varies according to the substance and to the time it has been in use: it increases in the case of glass to nearly double, between instantaneous application and a minute's continuance of current. It is plain that the substance acts in conveying the influence, and that some substances

allow influence to act through them better than others. Sulphur, an elemental substance, acts two and a half times as well as air which is a mixture of elemental substances, and gutta-percha, a compound, acts as well as sulphur: glass, also a compound, acts three or four times as well as air. Oil is a better insulator than air: but the influence through it is greater than through air. Air and glass are better nonconductors than ebonite or paraffin; but influence acts more strongly across glass than across ebonite or paraffin, and across these more strongly than air." Here is a nice set of riddles set up through misunderstanding. One would think after reading the above that there must be some inductive capacity in material, and there is nothing of the sort: this supposititious quality is merely a muddle of induction, conduction, and electric action in the condensed air on solids.

An entirely wrong point of view has been taken up for considering the "inductive action" imagined in the above. It is not material to our inquiry and we might pass it over and leave it to its believers, were it not that the investigation of it may help us to find out what we want to know, and we must omit no point that shows any chance of benefit.

If we consider the items given in the above quotation, we see that the better nonconductor a substance is, the better it conducts the influence through it: or to put it in another way; the more resistant the substance is to electrolytic action, the less it can be acted on by the æther vibrations of influence: and the less a substance acts by reason of the influence vibrations, the less it obstructs them and the better they pass through. A metal plate entirely obstructs influence because its condensed air coating absorbs the vibrations and becomes electrolytically active, and continues to absorb because the electricity produced is conducted away as fast as it is induced. A

plate of glass also has its liquid air covering influenced, but, as there is no conduction, the coat can only absorb the vibrations until it is saturated, and then the æther vibrations pursue their course without any more obstruction, and this is why glass seems to increase in *conduction* of induction by use.

When it is said that one substance conveys influence better than another, it conveys to us quite the opposite impression to what really should be given to us by the correct description of what happens; for the reality is that the one substance acts less than the other, and thus allows the influence waves to pass through it with less hindrance. There is no conduction of influence: the substances do no conveying of the vibrations which are dependent on the æther alone: if a substance acts it is to absorb the influence waves, and it is only when it cannot act that the waves pass through unobstructed, unabsorbed and unconveyed by the material.

Some substances have been found to obstruct the influence vibrations two, three, or four times less than air, and this appears to us at first sight to be a great difference, and assumes an aspect of importance till we consider that air acts several million times less than copper, when we become reassured, and can willingly admit that the vibrations may have some very slight action on the air and on these other materials that may ordinarily chance to come between the inciting and receiving conductors, but the action is so slight that its counteracting conduction effect on the conductors is utterly inappreciable. If clean air has any action at all it is due probably to the carbonic acid gas in it.

"The energy of self-induction = coefficient of induction × current squared ÷ two: or $\frac{C^2}{2}$ m: and it is supposed to be stored in the medium round the conductor. Change

in the value of current produces change in amount of this energy." The latter part of this quotation we can accept as palpably true, but not the idea of storage. We have seen that the air is scarcely or perhaps not at all acted on by induction, and there is no method resembling electric storage, that we know of, except chemical action or something equivalent, and which reacts strongly, often violently, and always unmistakably; the storing therefore cannot be in the air. The æther does no storage, and there is no other medium but the condensed air on the wires: this is the substance in which on the acting wire a current runs that originates the induction, and on the receiving wire in which the influence works to produce a current, so there is no possibility of storage in either of these. We may therefore safely reject the idea of storage of induction.

We will now gather together our facts and see what we have to go upon. A current in a wire produces induction. Induction is a vibration of æther produced by electrolysis. It reproduces electrolysis on other wire circuits. Not acting continuously but accompanying transverse movement of conductors and change of current. Acting on a length of wire directed towards its source, but not on a breadth when not moving. Stationary waves are some width apart. Interference produces stationary waves, and when a current passes on a wire there is a cause for interference in the induction waves sent out. We have seen what we believe to be actual cases of stationary induction waves, and all other wave motions produce stationary waves where there is interference. There are no connecting lines or rods to push or pull conductors.

With these for a basis we can only come to these conclusions, which are, that the electric action on the excited wire sends out two sets of radiant æther vibrations which by interference set up stationary æther waves which are broader than the conducting wires, and that when the

wires are not acted on it is because they are driven to that part of the wave where the effects of the vibrations cancel. And second that the electrolytic motion of the molecules set up by the induction on the responding wire, pushes that wire towards or away from the excited wire, and that the movement is not one of attraction or repulsion as commonly understood though it resembles what is meant by those terms. And we might add a third conclusion, which is that there is no such thing as attraction or repulsion as commonly understood, either in electricity, magnetism, or gravitation.

There is another point to be noticed. Two vibrating forces meeting pass one another unchanged: any interference that occurs is between the material waves that they have produced: when the forces emerge from the interference area, we can see that they produce again waves similar to those before the interference, only becoming weaker as they extend through loss of energy of the force. It is convenient to talk of vibrations acting on one another, but a vibration cannot be cancelled or changed or reinforced by a different vibration and only their effects on material may cancel, or change, or reinforce. Let us remember this.

STORAGE

CHAPTER XXIV

ELECTROLYSIS NOT STORAGE

Electric motor carriages for use on ordinary roads are supplied with electric power to drive them by "stored accumulators" carried on the car. The weight of these accumulators is a chief objection to the use of electric cars: but this will probably be rectified as there seems to be no apparent objection to the use of aluminium and a light chemical instead of lead as at present.

Such terms as storage and accumulator give one the idea that electricity can be collected and kept in receptacles from which it can be drawn off like water through the tap of a cistern. There is no electricity however in an accumulator. Accumulators are merely a sort of voltaic batteries, in which the metal used for both anode and kathode is lead. When they were first thought of they were made of solid lead plates, and they were brought to act as batteries by having a strong current passed through them for some time, and for several times reversed, until the surfaces of the plates, by the action of the acid in which they were dipped, were brought to a highly sensitive chemical condition. They are now more effectively and cheaply made. Two sets of perforated lead plates have their perforations filled with a paste made of red lead and dilute sulphuric acid: and they are arranged in an acid bath, so that the plates of one set alternate between those of the other set, but not touching: each set is joined up by a cross bar, and from these are wires to conduct the electricity to the driving machinery of the car. Either

set of plates may be taken as positive or negative to begin with: and according to the direction of the current sent through the apparatus to prepare it, the current reduces the paste on one plate and peroxidizes that on the other.

When the accumulator is used, the conducting wires are attached to the motor, and the reverse chemical action that is set up in the accumulator produces a current which continues with diminishing effect until the plates are brought to an equal condition, when they become inactive. "The accumulator current is of shorter duration than the charging current, but at the beginning of greater intensity." This we can quite understand and it would be a great improvement to the apparatus if by some device the chemical action and the current it produces could be regulated.

It will be seen from this description of the accumulator and its preparation for work, that there is no storage in it of electricity, but merely that chemical changes are produced by the electric charging, which, when they are allowed to react, cause a strong electrolytic action between the plates and consequently a strong current of electricity. The *charging* current is used, not because it leaves any of its charge in the cell, but because it prepares the plates better than can at present be done by hand. All the energy of the charging current is changed to work to perform this preparation, and the prepared accumulator works entirely by its own chemical action.

The nearest approach to storage of electricity is when a condenser or Leyden jar is charged. It really seems as if we had poured the charge into the jar and that it cannot get out again unless we give it a channel for escape. The outside, which must be in connection with the earth if we wish to give a strong charge, is charged oppositely as strongly as the inside, and the two charges hold one another by mutual influence. The surfaces bind each other's

electricities so strongly that there is no free electricity inside or outside; and if the plates of a condenser are separated they are found to be charged over both their surfaces and very much more strongly than they could have been without the aid of their mutual influence.

Now influence is produced by electrolytic movement. So we must conclude that this mutual influence between the charges on the two surfaces is caused by electrolytic movements in the liquid air coatings on the surfaces of the nonconductor intervening between the plates of the condenser, or, in the case of the Leyden jar, on the surfaces of the glass of the jar: and that the effect of the charging has merely been to put the molecules of the liquid air in electrolytic motion, or at any rate, to give them a tendency to such motion, and that the action is very similar to that in the motor-car accumulator. We will consider this more carefully further on, and will now examine some cases of apparent storage.

One of the great obstacles to fast signalling through submarine cables is that they act as condensers. Various expedients have been tried to better the condition, such as throwing an opposite charge into the cable with each signal to cancel the induction, or using very delicate instruments with a very light charge so as to produce as little induction as possible, but none of them has done more than slightly lessen the condition. What happens is, that a quantity of electricity is wasted in putting the inner surface of the rubber sheathing of the wire into an electrolytic positive condition, and helping it to put the outer water skin into an equal condition negatively, and in keeping up these two conditions. Perhaps enclosing the wire *loose* in a tube, so as to be surrounded with air, would cure it. Manufactured as the cable is, the wire has but a very small coating of liquid air, and the current has to force much of its way by electrolysis of the rubber,

which is several times more resistant than gaseous air and probably many thousand times more so than liquid air: so, even supposing this last to be over-estimated, the facility of carriage would be decidedly in favour of an air surrounded wire.

All condensers on being discharged by sparking between knobs at the ends of short, stout wires tend to overdo the work and to send a surplus to the opposite plate: this surplus is at once returned, with some small loss, as a reverse spark, and an oscillation of sparks goes on till equilibrium is established. The charge on the condenser, either sets the molecules of the condensed air coating in electrolytic motion, or it gives them a tendency to move in certain directions: whichever is the case, when the spark discharge takes place the molecules by relief are enabled to spring back towards the position of rest, and their unchecked impetus in doing so causes them to overshoot the mark and to move or incline beyond the position of stability, and in this way to leave themselves in a feebler condition than the molecules of the other plate which now have an excess of motion or strain, and in turn get rid of it by a discharge which is more forceful than necessary, and thus the oscillation of the molecules in decreasing amplitude in the two plates produce to-and-fro sparks till the plates have come to equal charges. This must be the manner of the oscillation, for by no possibility can an æther vibration be made to oscillate backwards and forwards, but a molecule or any other lump of attached material can be made to do so.

The above is the orthodox way of explaining the production of oscillating sparks, and it leads us to suppose that the molecules of an insulated surface are not merely under a strain when they are electrified, but that they are actually in slow motion, and the following are some facts which confirm that idea.

"Increase of the capacity of the condenser decreases the speed of the oscillation." With mere relief of strain, increase of area should make no difference, but with movement over a space we might expect a retardation when there was more ground to cover, and that it would cause a damping off of the more remote movement, the inertia of the molecules nearer the conductor influencing those further away, in the same manner that the prevention of oscillation by a wet thread or other damping conductor must be due to the obstruction in the conductor which reacts on the action of the molecules on the condenser.

However carefully conductors, condensers, jars, and suchlike things may be insulated, they lose their charges after a time, and the loss is greater at first and gradually lessens. Now the condensed air coating on a body is "electrified" by absorbing influence æther vibrations which produce some change in the molecules, and this change wears away as the liquid air molecules recover their previous condition, and in recovery they produce æther waves similar to those that they received: but to be able to do this the molecules must have electrolytic movement.

It might seem as though we were getting away from the subject of storage, which in truth we are in a way; for what these examples are leading us to, is, that there is no storage of electricity at all, but merely an electrochemical change produced by electricity, which in recovery, as exemplified by the materials in the accumulator, produces electricity which is entirely new. In fact that the motion that we call electricity when it has produced an effect ceases to be electricity or anything else, and any result from the effect, whether electric or otherwise, is a new production. One cannot bottle up a motion, nor is any of it left after it has been expended on work.

Air is often said to be stored with electricity, but it is not the air that is charged but the dust in it. The earth

is constantly producing electricity, most of which, owing to want of arrangement for separating the positive and negative, is at once cancelled. It is the damper and more active parts of the earth's surface that act as the anode in the system of production, and the drier and less active parts as kathode, and if the drier parts can be raised by the winds as dust before losing their positive charge, the equal negative charge is left on the earth uncancelled. In time the two electricities of the earth and air cancel one another by a lightning flash.

Flame is also said to occasion the storage of electricity. If we put the end of a conducting wire from a charged body into a flame, the body is discharged. The body, instead of getting rid of its electricity in the usual slow way by influence, finds an easier way and takes advantage of it. This means, according to the theories of the moment—and there are several—that the molecules of the gases of the flame carry away with them each a small store of electricity, either as a coating, or as an electron, or in some other way. The gases are in an active state of chemical change and are ready to accept any sort of vibrations offered to them, so they absorb the vibrations conveyed along the wire from the body: but the molecules in the flame are in too active a condition to receive them as slow electrical vibrations and take them to help the quicker vibrations of heat. There is no carrying away and no storage.

After a Leyden jar has been discharged, a residual charge remains in it, and the discharge of this can be hastened by tapping.

The amount remaining depends on the length of time the jar has been charged, and the sort of glass it is made of. "The residual charge is supposed by Maxwell to be due to heterogeneous substances having unequal conducting powers—or the molecules are subject to a strain

from which they do not at once recover." The first of these ideas does not appeal much to us: every electrolyte is made up of materials having unequal powers of conduction, but never is there any residue of electricity left in an electrolyte. The electricity in the case of the Leyden jar is on the two surfaces of the glass and is straining the glass in the endeavour to change it into an electrolyte to conduct the current: and on this account it is that time and the sort of glass count. But besides this there is a layer of some nonconducting substance between the foil and the glass which has been used for sticking the foil to the glass: and there are probably small patches where the glass is unconnected with the foil which patches would be charged by induction, and lose their charge by induction: and what effect the nonconducting material might have it is difficult to say—but this instance has not been brought forward as a proof of any fact or theory, as to show how careful we must be in experimenting and in interpreting our experiments.

The longer the jar is kept charged, the stronger is the residual charge, and the longer it lasts, because the glass takes on more strain and takes longer to recover.

Thickness makes no difference in the time of recovery, as the relief does not soak in from the surface but is simultaneous everywhere regardless of depth.

The amount of strain that can be produced by charging increases with the temperature, and the relief of strain is also assisted by heat, but in both cases only up to a certain limit above which the molecules become set in a new arrangement and there is no return. At 250° C. for soda glass the whole of the strain vanishes.

When the heat of a compound under strain is increased to the liquidity of the substance, conduction by electrolysis begins, proving that this sort of strain is incomplete electrolysis.

Now in the whole of this we can find no reason for supposing that there has been any storing of electricity in the glass, but merely that the electromotive force, or influence as it is named in these cases, has been used up in making and maintaining a strain in the glass, and that the glass molecules have reproduced a similar force in recovery from the strain, just in the same way as was done by the material in the accumulators, except that in their case there was complete action both in charging and in recovery, and in this case of the glass merely recovery from incomplete action.

There is no storage in a solid body charged with electricity, but merely a pseudo-chemical change in the molecules of its liquid air coating. These recover their former state either slowly by discharge of influence vibrations, or quickly by discharge of electromotive force. The charging force produces a condition: reversion from the condition produces an equivalent amount of force: but this is a new force and not the old one that was expended in work.

It is convenient to use such expressions as "charging with electricity," but there is no storing in any case but only a production of chemical or pseudo-chemical change: there is a movement towards electrolysis.

CONVECTION

CHAPTER XXV

CONVECTION AN INTERRUPTED CONDUCTION

We have not considered convection as a separate phenomenon in these chapters, but seem to have accepted it as most people do, as a self-sufficing fact: believing that any piece of material that happens to come into touch with an electrified body receives some of its electricity and carries it away with it. This is so plainly true that nobody seems to have thought that it wants any explanation or to have cared to know more than that it is so.

There were some small experiments which were shown us on our first introduction to electricity, which you will find at the beginning of most books which teach the subject, and by which we were supposed to learn what electricity is. No explanation was given of them beyond saying that the reason why some small thing was attracted and repelled from a charged body was, because the body that did these things was electrified, and that the small thing acted on was carrying away some of the electricity of the charged body. Teacher and students all seemed satisfied, and if questions have ever been asked, no one apparently has cared to record them, or their answers, or probably to know whether there were any answers at all, but to have taken the results as sufficient explanation. We however want to know the why of the whole business.

If a stick of sealing-wax is rubbed with a bit of fur, each of them, the wax and the fur, will be found to have acquired some property that they had not before, and this property we know as electricity, and that it is produced on the wax

and fur in the same manner as it is produced in the electrical machine, that is, by electrochemical action in the condensed air coating of one or other, or of both substances, and that if we test them we find that the wax is negatively and the fur positively electrified.

If now an elder pith ball (which acts better if it is gilded) or a small feather, hung by a silk thread, is put between the sealing-wax and fur, it will fly backwards and forwards between the two and continue to do so till their electricity is exhausted. The ball or feather is convecting. It flies, say, to the wax, receives from it a small charge of its negative electricity, carries this to the fur and with it cancels some of the fur's positive electricity, gets from the fur a small positive charge which it carries to the wax, and so continues to act till all the electricity in the wax and fur is cancelled, and they have become ordinary unelectrified bodies.

In a future chapter we will go more fully into the reasons for the attraction and repulsion which we see acting on the small objects, but just now we will inquire more particularly how the convecting of the electricity that these little bodies transfer is done. We will however first try a few more of these *simple* experiments.

If after rubbing the two together, the wax alone, or the fur alone, is brought near the pith ball, the ball will fly to meet it, cling to it for a moment, and then fly away and constantly afterwards avoid its approach. Here the ball has been attracted, has received a small charge of electricity, and because this charge is of the same sort as that on the charging body, the ball is repelled. Evidently the ball has suffered a change in some way, for the excited body first attracted it and since contact now repels it.

If, instead of the wax, a warm, dry flint glass rod be rubbed with a silk handkerchief and brought near the suspended pith ball, it will fly to the rod, leave it, and

elude its approach just in the same manner as it did the excited wax after touching it: and it will oscillate between the glass and silk in the same way as it did between the wax and fur. Evidently the sort of electricity used to act on the pith ball makes no difference in its actions.

Now if a glass rod excited by rubbing with silk, and a sealing-wax rod excited by rubbing with fur, are placed near and on opposite sides of the pith ball, it will oscillate between them till their excitation is lost: and the same will happen if the silk and fur are used instead of the glass and wax. There can be no doubt therefore that the ball carries small charges between the excited bodies, and that the charges are alternately of positive and negative electricities.

If either the excited glass rod or excited wax be brought near two pith balls which are suspended on different silk threads but touching one another, they will both fly to the excited body, leave it, and separate from one another, and will afterwards elude both the rod and each other. If the hand or any other earth-connected and conducting object be brought near the pith balls, they will fly to it and drop away uncharged, for it is only through insulation that they retain any charge.

If the two balls are suspended so as to hang a couple of inches apart, and they are approached by the positively excited glass on one side, and the negatively excited wax on the other, they will fly outwards one to the glass and one to the wax, then fly together, then return to the rods, and so continue till the excitement of the rods is gone.

And if the rods, used as in the last experiment, are instantly taken away on the balls touching them, the two balls will fly together, cling for a moment, and then fall apart quite indifferent to one another, all electricity having left them.

If conduction with the earth were allowed by using a

fine wire, instead of the silk thread, for their suspension, the electricity would escape instantly because the balls would then form part of a conductor. From this and the other experiments we may safely conclude that the material of which the balls are made has no significance so long as it is a material that conducts, and therefore that the action of the charges that they receive is confined to the condensed air on their surfaces as we have found to be the case in all the investigations that we have made hitherto.

It would appear then that the electrified body transfers a sort of strain to the molecules of the condensed air coatings on the balls or other small bodies, and that this strain is either positive or negative according to the electricity of the charging bodies, and that it is cancelled by the addition of an equal portion of the opposite strain. That if the positive strain is a surplus of electricity, it is not merely the addition of an inactive fluid to the surface coatings of the bodies, but an active motion, or incentive to motion, or as we call it a strain: and that the negative charge also produces a strain: and that both of these act so as to cause a particular motion on the bodies such as will produce influence vibrations in the æther between the bodies, which vibrations so act on the molecules of the condensed air coatings that the excited molecules push the bodies together or push them apart, the motion of the æther being converted to motion of the molecules.

The old statement that similar electricities repelled and dissimilar electricities attracted through space because they were electric, belongs to the unmeaning explanations of old myths. No counteraction can occur between separated bodies unless motion is carried by material through the intervening space, including in this term the material æther: there is no such thing as action at a distance.

The charges on the bodies, if they are not allowed to touch, gradually disappear because they produce that

motion in the surrounding æther that is called influence. If the strain did not produce a certain amount of motion of the molecules coating the charged body, that is, if it remained an inelastic resistance and nothing more, it could not produce any motion in the æther. We must conclude therefore from this and other instances that the strain produces some motion of the molecules.

Part of the influence motion of the one body acts on the other, and produces a new movement of the molecules of the air coat, and that movement causes the body to move one way or the other. The direction of the movement of the body depends on what sort of electricity sent out the influence waves, but beyond this electricity has nothing to do with the action, but only the mechanical movement of material on the body moved.

If a pointed wire is added to the conductor of an electrical machine, the electricity produces a wind in the direction of the point of the wire. Now if we stir up the dust of the room with a broom, and arrange the wire so that its point is illuminated by a ray of light that makes the dust motes visible, they will be seen going leisurely towards the wire and then darting away from it. They go to it unelectrified, receive a charge, and dart away repelled, the repulsion being much aided by the electric wind. They are convecting. The molecules of condensed air on the surfaces of these dust particles have received an electrical impulse from the molecules on the wire. Had the dust particles been arranged in a continuous string, they would have formed a conductor, and the impulse would have sped away: as it is, the motes being insulated bodies the impulse remains on each as a strain.

The strain is an impulse to electrolysis received by the condensed air molecules, which can get no further than the limits of the insulated convecting body, and we may therefore call convection an interrupted conduction: an

incipient electrolysis which is produced by any charge, positive or negative.

The convecting body must be a compound body in which electrolysis can act: no elementary body can convey electricity. When a ball of elementary metal conveys, it is not the metal that is doing the work, but the condensed air on it, or the product of some chemical action that is going on, on its surface. It is the same with dust; and moisture, if it conveys, does so because it acts electrolytically. Clean air, such as we commonly call dry, neither conducts nor convects, because the moisture in it is in the form of molecules, which, though they are compound, cannot move their components electrolytically: but in damp air the moisture is in minute water drops, in which drops electrolysis can act as easily as in a bucket full: and the only cause for doubt about electrolytic convection by the water in air is that an ordinary charged body would probably not have enough force to overcome the resistance of water to electrolysis.

What we have now learnt is that convection is the transfer of an electrolytic strain; and that the convecting body is driven away from the charging body by influence vibrations.

In performing the little experiments mentioned in this chapter, it is advisable not to handle the fur or silk too freely, or their charges will be conducted away. To prevent this tie them to glass rods or pieces of dry stick.

ELECTRICITY

CHAPTER XXVI

ELECTRICITY CAUSES A MOTION OF MATERIAL

We have now studied the production and action of electricity in many ways and should be ready to answer the question. What is electricity?

Our usual practice has been to collect data and to deduce our statement from them, but we have already done this and studied electricity from every point with all the data available, so now we will assemble our deductions, recalling the principal facts, and on these deductions will base a conclusive judgment.

One deduction that will be found as the last word in our study of every separate subject is, that electricity depended on electrolysis, and that being so, electrolysis should explain what electricity is, therefore we will closely examine its action.

To prevent any mistake as to the meaning of the terms we employ in the inquiry we are now about to make, we will suppose that we are examining and speaking of a voltaic cell, with zinc and copper electrodes, and with water acidulated with sulphuric acid as the electrolyte.

In such a cell the action is as follows. The acid molecules of the electrolyte, that is the oxygen of the water, and the sulphuric acid in the water, that are touching the zinc, combine with it, and this sets free basic hydrogen molecules from the water; and the acid molecules next to these basic molecules so set free combine with them, leaving their companion basic molecules: and so at each combination at the zinc an interchange and combination is made

all through the liquid to the copper, where basic molecules of hydrogen, deprived of their acid companions, are set free. This interchange is the electric current and it passes through the liquid with great speed, while the molecules, at each interchange, move one molecule's breadth, whatever that distance may be, say a hundred millionth of an inch: and the entire movement, though actually progressive, may be called simultaneous for such short distances as we can observe in our experiments.

It was for long supposed that electricity travelled through electrolytes and along conductors at the same speed as light, but this has been found to be an over-estimate. The experiments to find the velocity of the current have hitherto been made with wires, that is with the liquid air coatings of wires, and the rate of conduction has been found to be at the rate of about twelve hundred miles in a second. If a compound substance with less density and less cohesive inter-attraction of molecules could be found, the rate would doubtless be greater, for obviously the rate must depend on the molecular resistance to change, but probably there is no more easily acted on substance than liquid air. The density of water is less by more than a half, but its molecules are very strongly chemically combined and must therefore offer much more resistance to separation and a slower transmission of current than the molecules of liquid air held together by contact alone without chemical combination.

The molecular interchange in the electrolyte is not produced by any wave of the liquid. The fastest vibration of water is that of sound, which travels through it at the rate of four thousand feet, or about three-quarters of a mile, in a second, while the vibration that causes this electrolytic interchange travels perhaps twelve hundred miles in a second. It is a vibration of the æther that is associated with the molecules of the electrolyte, and is produced by

the shock of the coming together of the acid and basic molecules at the anode.

Each molecule as it joins its new partner, whether at the zinc or in the fluid, is drawn to it by cohesion with constantly accelerated motion, so that they meet with a little clash: this sets the æther vibrating and this vibration is the electromotive force, and it is through its propagation as a vibration that the molecules separate. Each vibration produces one molecular change, and each combination one vibration.

The molecules are separated by the æther vibrations and they reunite by chemical attraction, and the double action of the molecules is the current movement, and this electrolysis and the electromotive force, together are electricity. Electricity is due to the conjunction of acid and basic molecules and every phenomenon of electricity can be shown to be produced by this.

Electricity must not however be confounded with influence, induction, or Hertzian waves, which are produced by electricity and are forms of electromotive force as has been explained in the chapters on these subjects. Neither chemical action of itself, nor electromotive force of itself, is electricity. Nor is electricity the same as magnetism so far as we know.

There is a general agreement that electricity is not material. Its speed of translation is very great, and no material has been found in any situation with speed at all approaching it. A meteor entering our atmosphere with a speed of twelve miles in a second is consumed at once, and as we have no authority for assuming that material in any condition is not subject to the ordinary laws of nature, we must conclude that it is impossible that molecules should travel a hundred times as fast with no sign of disturbance of any kind, and we may reject any idea that assumes any faster movement of these particles

than the very slow movement of them that has been discovered in electrolysis.

Electric force has an attachment for material: it is inseparable from material: but it uses it as a path, or as we say, as a conductor, and not as a crutch or vehicle. The following will illustrate the meaning of this. When we strike the end of an iron rail with a hammer, any light weight, suspended by a string and touching the other end of the rail, flies away from it at the instant, apparently, that we strike: and although we have seen no motion in the rail, there certainly has been a minute movement of all the particles of iron in *succession* from the point struck to the other end: and while the movement has passed through in an instant, no particle has moved sufficiently for us to detect movement. The force of electricity acts like this force of percussion: it uses the material to conduct it but is no part of the material. It is a force dependent on and inseparable from material, but no more material than any other force is. Electricity is a swift force of electromotive vibrations combined with slow electrolytic material movement: and these two movements are interdependent on one another: electricity cannot pass beyond material and there is no electricity in space: there can be none in the æther because it is not electrolytic.

Some persons write about force or movement in a loose way as if these things could exist without matter and we must beware of ill-considered wording. For instance, one might carelessly say, that a point having little mass, has little attraction of gravitation, or cohesion, and that therefore "electricity escapes from it." Which sentence as it stands might be taken as a statement intended to convey the idea that electricity is material: for material is subject to gravitation while motion is not. There are several sentences which should occupy the place of the word "therefore." What escapes from the point is

material oxygen or nitrogen, and their movement produces a wind, which carries the dust of the air with it, and this discharges the electricity by convection.

* * * * *

The electric force that decomposes and that which is evolved by the recomposition of a certain quantity of material are alike. Faraday found that "the chemical action on one equivalent of amalgamated zinc by dilute sulphuric acid, produced that quantity of electricity which passed through water decomposed one equivalent of it." This shows that electric force is an extraneous force and not any inherent property of material.

There has of late been a return to the emission theory for all those phenomena that we have been taught to consider as the products of vibration: there is even a much advertised book on the materiality of sound; and electricity being a somewhat misunderstood phenomenon comes in for much theorizing in that direction. Matter is made, some scientists say, of molecules, these of atoms, these of corpuscles, these of centres of electricity which are not matter at all, but motion. Others suppose electricity to be a "resident property of the molecules of substances, the positive and negative together in a combined state of neutrality, but with mutual antagonism." A motion antagonistic to itself is not an easily intelligible motion. And what is a resident motion? Motion must be given to any object, or it is motionless; and we cannot credit the inert molecule with any power either to produce, or to renew, or to bottle up motion. Latent force is a myth; the force that raises a weight is not bottled up in the weight, and there is no sunshine in either coals or cucumbers.

In all our examination of our subject we have seen no faintest sign that material has any electricity of itself,

but always found that it has to be manufactured for it: and always electricity has appeared as a motion and has had to be produced by motion, and according to the motion supplied has been the out-turn of electric motion. Ask an electric light company to produce current without an engine! The force put in produces the force given out.

In electricity the force put in is always chemical attraction which gives out a force that separates the components of the molecules of the compounds on the whole circuit, and they must separate in such a way that they take opposite roads, and as the only material conducting on wires is liquid air, the oxygen and nitrogen must move in opposite directions, and if occasion demands be discharged as separate materials.

Many examples can be given to prove this true, that oxygen moves along and is given off from a negative conductor, and nitrogen from a positive. We have already had one instance where the crossed wires from the terminals of a voltaic battery became, beyond their crossing, the one red hot from combination with the oxygen moved on to it, while the other on which the nitrogen was projected remained cool. How could this be explained with "aggregates of electricity"? If electricity had any heating power it would make the whole conductor hotter than the part of wire where only a portion of it could be supposed to travel, and would heat both projecting pieces and not that alone on which the oxygen moves. The heat is produced by the chemical union of the oxygen with the material of the wire.

Then there is the separation of oxygen and nitrogen in a Crookes' tube: the oxygen is discharged from the kathode and a dark space which is nearly pure nitrogen surrounds it.

Another proof is the action in the air space between the carbons of an arc lamp: the "positive carbon becomes much the hotter and burns away twice as fast as the

negative one," because by electrolysis the oxygen is moved towards and combines with the positive carbon. With alternating currents both burn equally.

When a Leyden jar is discharged through a resistance that quenches oscillation "the positive terminal is more heated than the negative," because the oxygen is moved to the positive terminal and combines with it. With oscillating discharge both terminals are heated.

The knobs of an oscillator oxidize rapidly in air, because the oxygen is separated from the nitrogen at the faces of the knobs, and combines with the metal. By passing the sparks in oil, this is avoided, because the substances that compose oil do not act on the metal of the knobs.

Professor Nipher has lately made some experiments with zigzag wires, connected with the ground, through which strong interrupted currents were sent from an eight-plate static machine worked by a motor. Photographic plates in hard rubber covers were put at the angles of the wire, some on the ground side and some on the machine side of the angles.

With the negative discharge from the machine "the plates on the ground side of the angles are much more strongly fogged than those on the machine side." The particles that produced this effect could pass through $\frac{3}{16}$ inch rubber, but not through glass however thin: thus proving that they are material and not motion. They were molecules of oxygen and they passed through pores in the rubber but found no pores in the glass.

With the positive current and a rubber cover only $\frac{1}{16}$ of an inch thick "9,000 spark discharges produce about the same intensity of image, as a single spark in the negative line. And here the effect is vastly stronger on the machine side than on the ground side," showing that there was some very slight reverse current due to polarization.

These effects were attributed to the electron, and Professor Nipher calls attention to the "fact" that the electromagnetic action of these electrons on each other "in a nonoscillating discharge is sufficient to account for the thinning out of the spark towards the positive end of the spark." It is a fact that the spark thins out towards the positive end, but to say that electromagnetism (of which there is no proof) acting on electrons (which have no existence) is a fact, is mere fancy. If there were any action of this sort, the effects produced on the zigzag wires by negative and positive discharges should be equal, for we cannot suppose the electrons could be less active in one case than in the other.

The fogging of the plates is caused by molecules of oxygen whose momentum carries them off the wires at the angles. And the nitrogen molecules, whatever their number may be that are shot off, can produce no effect on the photographic materials.

The following is a particular problem, which we have already noticed, in discharge by flames. "A magnesium flame discharges negative electricity but not positive electricity." We can answer this if electricity involves the movement of oxygen and nitrogen on the conducting wire, but not otherwise. The burning magnesium is combining with oxygen and nothing else, and its flame encourages the negative current by taking up the oxygen brought by it: but it has no use for the nitrogen sent by a positively electrified body, and the electrolytic action being checked, the positive current is stopped and the positively charged body left undischarged. An ordinary flame, in which there is some electrolytic movement can encourage either current, positive or negative.

The following are three cases exemplifying these actions. "Violet light falling on a metal in air electrified negatively discharges it." Because it accelerates the separation of

effluves from the metal surface, which unite with the oxygen that collects on negatively electrified surfaces.

"But it does not discharge the metal if positively electrified." Because the associated nitrogen and the metallic vapour cannot combine.

"However violet light falling on peroxide of lead positively electrified in hydrogen discharges it." It reduces the lead oxide and then the oxygen and hydrogen can combine.

In two of these cases material is emitted which, by electrolytic movement, can exhaust the electromotive force: in the second instance there is no action because only elementary uncombinable substances are present.

We cannot find discharge without the movement of electrolysis. "A red-hot cannon ball cannot be positively electrified, but may be negatively—white hot it retains neither." The nitrogen driven by the positive current cannot compound with the hot iron emanation, but the oxygen of the negative current can, and renders it electrolytic. The actinic vibrations of white heat prevent chemical combination and therefore prevent the acceptance of electricity.

* * * * *

There is one point that you will have noticed in our experiments, and that is that the molecules of condensed air, or of any other electrolyte, when once set in motion, have some persistence of motion, by which they may be carried even beyond the influence of the electrolytic movement.

If a very strong static current is passed through water, certain currents are set up which can be seen if the water has some insoluble powder mixed with it and if proper arrangements are used. The electrolytic action in the water is for the hydrogen to pass towards the positive and

the oxygen towards the negative anode, and when this movement is pushed very vigorously, it can carry the water with it in two slow, but visible, streams. It requires a great electromotive force to do this, and Mr. Armstrong succeeded in doing this with his powerful steam electrical machine, as recorded in the following description of his experiments.

With two wine glasses, four-tenths of an inch apart, filled to the edge with pure water, and connected by a wet silk thread the ends of which were coiled in each glass; when a negative current was sent into one glass and the water in the other glass was connected with the ground, "a slender column of water enclosing the silk in its centre was instantly formed between the glasses: and the silk was quickly all drawn over into the positive glass"—that is to say it went propelled by the hydrogen movement.

"The column of water persisted for a few seconds without the silk: and when it broke sparks passed."

"When one end of the silk was made fast in the negative glass, the water diminished in the positive and increased in the negative glass."

"By scattering dust on the water surfaces it was found that there were two concentric currents, the inner flowing from negative to positive and the other positive to negative."

Mr. Armstrong succeeded in "causing the water to pass between the glasses without the silk for several minutes and at the end could see no difference in the quantity of water in each glass. The two currents, when the inner one was not retarded by the silk, were therefore nearly, if not exactly, equal." The two hydrogen molecules have only the same bulk in combination as the single oxygen molecule and can do no more work than it.

We have seen also the actions of inertia and separation by electrolysis in the discharge in a Crookes' tube. The gas molecules travel by electrolysis, but are thrown out of the current when they condense for a moment on the glass. The oxygen molecules begin their course in a *straight* flight and keep that line through inertia.

The aggregate motion of the molecules in electrolysis is certainly very slow, but each of them probably moves in its tiny course with comparatively great rapidity, and therefore acquires some motion of inertia. It is this inertia probably that gives an alternating current its power of conduction. "The continuous current loses energy if conveyed to a distance. An alternating current changing direction 60 to 100 times in a second can be sent on ordinary wires ten times as far with half the loss. The low electric pressure (voltage) of the direct current is changed to an enormously high pressure in the alternating current, which can overcome the resistance of the wire."

The last paragraph seems as though it was intended to convey an explanation, but it gives us no why or wherefore for increase of action or of pressure, nor is there any proof that there is increase of pressure. Pressure comes from force used, and there is no more force used in sending the one current than in sending the other. But conceive now that the first impulse of the alternating current has put a strain, beyond the point that its complete electrolytic action can reach, on all the molecules as far as its influence can reach, and that all these influenced molecules are inclined in a forward direction, then when the current is reversed they swing back, through release of strain and through inertia, to nearly as far as they had gone forward. Now, when the current again goes forward, it finds nearly all its work done for it by the next forward swing of the molecules, and it can push on for another length along

the line. So with less resistance in front the voltage is made to seem to increase.

A great deal of mathematics, including the application of Bessels' functions, is used by scientific electricians to assist the understanding of this fact, that an alternating current goes farther than a direct current on a wire, but the whole of the difference in plain words is, that in one case a rhythmical force is applied and in the other a plain push. And as the whole of the current is on the surface of the wire, Bessels' functions which refer to the whole depth of the metal surely add a superfluous inaccuracy.

* * * * *

From what we have learnt from the study of the numerous and very varied examples that we have been able to see or hear of, we must conclude that electricity is a motion that has to be produced by the work of chemical combination: and that it is no part or property of matter.

The movement of chemical attraction of itself, or assisted by mechanical force, produces a shock in the oxidized molecule: this causes a vibration of the associated æther: and this produces electrolysis which passes as a wave through the circuit. Without these movements and an electrolytic circuit to carry on the movements, no current of electricity can be produced.

The word vibration is used for the movement induced in the æther in electrolysis because there is no other word that is convenient. If we have a ball suspended by a string or fixed at the end of a spring, and we strike the ball, it will move backwards and forwards and make what is called vibrations: but the same stroke given to a ball lying unconnected will cause no such vibrations of it. It is this latter form of movement that has here been called vibration in the case of the æther action in electrolysis—

there is a forward movement and no return, and each movement produces just so much effect as the effect that produced it—the movement on one molecule produces a similar movement in the next molecule and goes no farther, because its force is used up in the reproduction of movement.

ELECTRICITY

CHAPTER XXVII

FLUID IS THE CONDUCTOR ON SOLID CONDUCTORS

THERE is no need for us to go over again the old story and show proofs that substances have coatings of liquid air upon their surfaces, and that when these coatings are dissipated by heat, that the substances refuse to accept electricity, and are useless as conductors: so we will, without more words, consider the manner in which electricity is carried along a wire by the electrolytic action of the molecules of the liquid air on the wire.

From all the experiments that we examined in the study of conduction and elsewhere, we came to the conclusion that electricity is conducted along wires by electrolysis in their condensed air coats, in the same manner as it is conveyed through the electrolyte in a voltaic cell, and that any action on the metal of the wire, resulting from the passage of the current, is due to the interaction of the metal surface molecules with the condensed air coating.

If we work an electrical machine and connect the chief conductor as well as the amalgam with the earth, thus making a complete circuit, all the electricity we choose to make goes into the earth along the wires and is cancelled, and there is no result except that the conductor wire is somewhat heated. This does not result from any electrical heat, but from the electrical action, which entangles or brings in some way some of the surface molecules of the metal into combination with the liquid air upon the wire: their combination produces contraction, and their contraction evolves the heat which is transferred to the wire.

The more easily the surface molecules are detached, the greater the waste of electricity and the greater the heat. The finer the wire, that is the smaller the condensed air channel of conduction, the more the metal is called upon to act and the greater the waste of metal and electricity, and the greater the heat. The wire if very fine is quickly burnt away: it is not melted but is destroyed by chemical combination of the metal with its fluid coating.

"None of the heat of the wire appears in the cell." Because all the heat produced in the wire is local and soon dissipated into the air: and there is no heat from the action in the cell, because the æther vibrations produced by the clashing of the combining molecules are not heat vibrations but impulses of much greater length than the longest heat vibrations. Electricity can give no heat directly, but makes it by the chemical action that it helps to bring about on the wire or other conductor. The heat of the spark or of the lightning flash is not electrical but chemical from the burning of the conducting air. The heat of the arc light is chemical from the burning of carbon and air. There is little heat on a good conductor as there is little chemical action of the metal, and all the light and heat of electric circuits is due to chemical change of the conductors, and almost certainly to that alone, for friction, which is sometimes quoted as a cause, is also an inciter of chemical combination.

Wires that are used to convey electricity become what is called rotten after a time, because the cohesion of their particles is reduced, and this is sometimes ascribed to the current, and quoted as a proof that the substance of the wire carries the current, though how it is supposed to act is not told. It is much more probable that the weakening of the wire is owing to alternate heating and cooling. A piece of iron alternately heated and cooled many times can be made to grow forty-five per cent. in bulk: and its

loss of cohesion and consequent rottenness is certainly proportionate.

There is always some loss of electricity on the conducting wires. Even if we had a perfect conductor the current could not pass along it without some loss. Each impulse of the electromotive force exhausts itself in the work of dividing a compound molecule, and though each reconstruction of a molecule *should* revive the force, we cannot but think that the overcoming of inertia must dissipate some of it; and besides, all along the conductor some of the force is used in setting up induction waves and is thus radiated away. But for these we might have perpetual motion if we could find a perfect conductor, as it is our materials act very imperfectly and variously and some resist the strongest impulse that can be brought to bear on them, still on a good conducting wire electricity will go far.

In what way can an electron act to carry the current or to resist carrying it? It is supposed to be a little pellet shot out of a molecule, or else wandering between the molecules. In an inch of electrolyte there are a hundred million molecules to obstruct the shot: can you suppose that this little cannon has force to drive its shot through this inch, not to mention a thousand miles! Or, looking at our calm electrolytes, can you believe that material is rushing through it at the rate of twelve hundred miles in a second. Only with æther vibration can such velocity be obtained.

If the molecule can fire its electron to even the smallest distance, then why should it require many hundred times more force to send it through gaseous air, than through the sixteen hundred times denser liquid air? And how is it that a little silk thread wound round a wire, or the thinnest sheet of paper, is able to stop conduction? These things stop the electricity, not by entangling electrons,

but because the condensed air on their fibres does not form a continuous liquid conductor.

In no direction do we find any indication that electricity is material in the remotest degree, while all we learn about it points to its being motion only.

The *rate* at which a current passes along a conducting wire has almost nothing to do with its material, or its length, or its thickness. "If an oscillating discharge is sent over a bifurcating wire the ends of which are set close together, there will be a spark between them if the two branches are of different lengths, but if they are equal, there will be no spark, whether the two are of the same or different metals." The rate at which the vibrations travel through the liquid air on the conductors is unchangeable. All that the material has to do with the conduction of electricity is the distance that it will conduct before its resistance changes the impulses to other work. When they say that the rate of the current through deep sea cables varies from ·932 to ·292 of a second for a thousand nautical miles, these measures really represent the time it takes to charge the covering sheath of the wire inductively in successive lengths by the diversion of the electromotive force. The rate of the impulse, while it remains an impulse and unconverted to other work, remains unchanged.

According to some theorists "the medium round the wire is the conductor of electricity, and the wire is merely a guide to the current flowing outside it": and when there is resistance and waste of energy by change into heat, it is said to be due to "the energy flowing laterally from the medium into the wire." As æther is a perfect nonconductor, the medium referred to must be air, though how this can be imagined it is difficult to understand, for we know that air is one of the worst of conductors, and requires an intense force to compel it to act, and does so with intense heat, and light, and noise, whereas a good conductor

requires no coaxing, but at once conveys away enormous charges with scarce a sign to show for it.

In those interesting experiments, with electrified wire gauze, invented by Vanderfliet, we saw that the force acted on the outside curves and was wanting in the hollows. If any extraneous medium had the regulation of the electricity about the gauze, it should act indifferently everywhere. One can understand that if the electricity is an affair of the gauze, that it should by its mutual repulsion leave the inside of the loops; but if it is extraneous, why should it be ruled by the gauze, why should it not by its repulsion leave the gauze altogether? The electricity acts as an appendage of the gauze and not as if it worked in any separate medium.

And then about resistance. What would make the air, or for that matter any conceivable outside medium, round an iron wire, resist the current six times more than the same medium when round a copper wire: and why should electricity flying in one direction, take the trouble to turn its direction at right angles merely because of a change in the metal of the wire conductor? And why should heating a metal conductor prevent its acting not only when hot but for some time after it is cold, if anything but the liquid air coat on it does the conducting?

*   *   *   *   *

The molecules of air are mixed, not compounded, but conduction on metallic or other conductors requires that they should be joined in groups in some way, in order that a dissociation and recombination similar to electrolysis should occur to enable the current to travel, and this collection in groups appears to be what must actually be the arrangement, for if the gases of our air were not associated somehow, they would as surely separate as oil and water, the heavy oxygen would settle below and the lighter

nitrogen would rise; but air, whether taken from heights or depths, has been found everywhere to have the same invariable percentages of these gases. Professor Lodge says that the "molecules of air contain approximately 25 to 28 corpuscles." That is to say, putting it into the language that we have been using, and substituting molecules for corpuscles, the air is probably composed of groups of five oxygen and twenty nitrogen molecules, held together as a compound molecule by mutual cohesion, but not chemically combined: and this combination is not changed when the air condenses to a liquid; the compound molecules are then merely liquid groups instead of gaseous, but being some sixteen hundred times denser as liquid, they hold together with so much the more cohesion.

Chemical attraction no doubt causes deformation and extended contact of the molecular surfaces pressed together, and a spark in air produces this actual chemical combination as is shown by the nitrous products resulting: but in liquid air the cohesion of the groups is probably due to mere contact without deformation, and this accounts for the ease with which electric force separates the members of the groups and also shows why liquid air is the favourite conductor of electricity, which is simply because all other compound liquids have chemically compounded molecules which are less easily acted on.

All the evidence shows that electricity is conducted electrolytically in the condensed air on wire conductors: and in no case can there be such conduction unless this fluid or some other is present. Doubtless other fluids would act similarly and more or less effectively if they were on the wire, but they are generally absent and the condensed air present.

Fluid is the conductor on solid conductors.

ELECTRICITY

CHAPTER XXVIII

INFLUENCE

FORCE cannot act without the assistance of material, and the only way in which force can act at a distance is by movement of the intervening medium: and where the force acts without movement of sensible material, it acts by vibration of the insensible æther. To suppose that the action of influence at a distance is caused by such objects as ejected electrons, or other emitted material, is to return to old and exploded emission theories which present knowledge has made impossible of acceptance: and as it is equally futile to suppose that a perfect fluid like the æther should have any translational power, we must look for the cause of attraction and repulsion of electrified bodies elsewhere than in any mechanical transmission, except only in that of vibration of æther.

Some people seem to think that the attractions and repulsions between electrified objects are due to lines of force, and speak of these lines in such a way as to suggest that they are material rods which can act in the same way as an oar or boat-hook when used to stave off or draw a boat to a ship's side: but Faraday when he invented these terms surely meant direction and nothing more. The force of influence is a vibration of the æther, and neither the æther nor its vibration has power to push or pull material. Still these rays of force produce vigorous and immediate movement of material along their lines of direction: so it is plain that some action must be set up on the material which causes the material to move: and

as there is no pull or push in the medium, the pull or push must be an action of the material acted on: and as æther vibrations can only act on molecules the action of the material must be due to a molecular movement on its surface. You may liken it to the working of the wind on the sails of a ship: they are attached to the ship and move the ship one way or another according to their arrangement: the wind acts on the sails and they push the ship. The vibrations act on some part of the material and that pushes the whole material.

The first lesson we learnt in electricity was, to rub a stick of sealing wax on our coat sleeve and hold it over small scraps of paper to see them fly up to the wax and then fly off again: and next we attracted a little feather hanging by a silk thread, which after it had left the wax could not be caught by it again. We read of these little experiments in every book on electricity, and are told, that it is because of the attraction and repulsion of electricity that these things happen—and nothing more. There is no attempt at any explanation: and yet in the explanation of these anciently discovered facts lies the whole explanation of electrical influence and induction: attraction and repulsion.

Before we seek an explanation of these facts it is necessary that we must know what the action is that is going on upon the surface of an electrified body and that is producing the movements of attraction and repulsion of the body.

A body can be charged with only one sort of electricity. On every charged body there must be some movement going on to produce influence vibrations: the movement is over the whole body, because the influence radiates from all parts, and in all directions: it is a slow movement, for a charge will last for hours though it is dissipated in an instant by conduction; all movement is reciprocal, if

you push or pull, you push or pull yourself with equal force and in the *opposite* direction to the movement you give: the proof plane shows us that the action on electrified bodies is more intense at the ends of elongate bodies and on the edge of a plate than at its middle: therefore the molecular movement is outward from the middle and being equal on opposite sides it cannot move the body: but if the movement at any part could be increased it would move the body in the *opposite* direction to that in which the movement itself moves.

Remembering these generalities let us now consider the particular cases.

The negatively electrified wax that we are using, sends out negative influence waves that cause an electrolytic movement with separation of the positive and negative electricities on the feather, and by increasing the negative movement away from the wax the feather is pushed towards the wax.

On touching the wax, the positive electricity on the feather is cancelled by some of the negative on the wax, and the whole feather is then negatively charged. Any influence vibrations sent out by the wax to act on the feather, will now incite the negative molecular movement on the nearer part of the feather more strongly than it can that on the further side, and the feather will be pushed away from the wax.

The common saying that like charges repel and unlike attract, is quite wrong: the charges have nothing to do with it except the providing the influence waves that produce the apparent attraction and repulsion. The charges on two bodies similarly electrified send out influence vibrations that incite the molecular movement more on the nearer sides than on the further sides of the charged bodies and the bodies are pushed apart: while the influences of unlike charges incite each a molecular move-

ment away from the exciting body and the bodies are pushed together.

In fact there is no such action going on as attraction, for what seems to be attraction, and repulsion as well, is a pushing about of material, and all that we see might be called propulsion.

We can now understand why a charged bubble expands; it is not by any expansion of the air in it, nor by push of rods by force, but because the influence waves in the interior mutually intensify the molecular movement towards the interior and thus push the material outwards.

The following is an extract made from a report on atmospheric electricity in America, and refers to the stream issuing from a Kelvin collector during a storm. "Previous to the lightning the stream from the collector was twisted and split into many fine threads and sprays, but instantly with the flash it became a single jet, and remained so for a few seconds, then gradually becoming more distorted until another flash occurred: there was also cessation of sparking between the collector and the ground wire at each flash." The stream was highly charged between the flashes, but it carried no electricity when the flashes had for a time restored electric equilibrium. The reason for the distortion and separation of the water jet, was the action of the influence waves, which acting on every irregular depression on the surface of the jet forced it to divide.

It is by the driving away produced by unlike charges that dissimilarly electrified bodies are pushed together and their electricities cancelled, but whenever by the interposition of a nonconductor the cancelling is prevented, the different electricities are held, pressed as it were, against the two sides of the nonconductor, and charges so placed are said to be bound: they interact mutually by

means of their influence vibrations which pass through the nonconductor and in this way they will accumulate on the faces of it in much greater strength than they can be made to do as single charges.

The positive charge in a Leyden jar sends out waves of influence, which, carried by the æther, pass through the glass and influence and carry away the positive charge on the other side of the glass, and leaves the negative on which they have no action upon the glass, and mutual influence thus pushes the unlike charges together as near as possible.

If two Leyden jars are charged, the one positively and the other negatively, and they are placed with their outer coatings, which are negatively and positively charged, touching one another, they do not discharge one another. The outer charges have been collected by the influence vibrations sent out by the inner charges, and are only sufficient to satisfy the mutual action of their rays of influence, and none can be spared to act elsewhere.

When a conductor that is insulated is charged by influence, an electrolytic action is set up in the molecules of the liquid air upon its surface, and according to whether the influence is positive or negative, so is the direction and position of the negative and positive action produced. If the influencing body is positively charged, its influence waves cause a positive movement on the influenced conductor away from the body, and a negative movement towards it, and *vice versa* with a negative charge.

If the conductor is isolated there can be no current: there is a division, or inclination of positive and negative molecules towards the ends of the conductor and as they can get no further the current is stopped: but the tendency remains and may be called a strain or any other like name. Electricity moves swiftly, but the strain is immovable except for the slight way that it makes to fill up losses by

induction: it may be strengthened by additional influence, or it may fade away through loss by the influence itself sends out. For it is plain that there must be a certain amount of slow work going on upon the insulated conductor to produce the influence waves emitted, and the work must be done by the strain, and the strain must lose.

"Even if the conducting wires of a cell are not joined, the wire of the zinc is negative and of the copper positive, there being a tendency for the zinc to oxidize and drive electricity through the cell." Here what we call a strain is called a tendency, and the same tendency is found in all isolated bodies charged with electricity, or arranged to produce it. The ends of a voltaic pile are differently electrified: the zinc end positive and the gold end negative; and this charging of the ends could not have happened unless there had been a tendency to movement in those directions. "The action of the voltaic pile is cumulative and nearly disappears on discharge." This accumulation and charging of the ends has happened, although there has been no current, because there has been a strain and gradual movement due to it.

The eye can detect no movement in the electrolyte in a voltaic cell, but the fluid is found to be doubly refracting from the strain produced by the electromotive force. And "glass when subjected to a severe electrostatic stress undergoes an actual strain which can be observed by the aid of a beam of polarized light." This change in refraction takes about half a minute to attain its maximum in solids, from which it gradually dies away when the electromotive force is removed, but in liquids both effects are instantaneous.

What then is it on which these strains act, and what are positive and negative molecules? They are certainly substantial or they could not push or pull, and they are substances that by intermixture become some ordinary

unexcited fluid. There can be no doubt that in the case of influence the materials acted on in liquid air are nitrogen and oxygen, and in water that they are hydrogen and oxygen; and if we go over this chapter again and substitute these names where necessary, we will arrive at a very clear understanding of the subject.

According to our ideas, the water molecule is made up of one oxygen and two hydrogen molecules combined into a nearly spherical globule, which, when unacted on, always floats with the hydrogen uppermost. There is no difference in the sizes of the oxygen and hydrogen molecules before they combine, but when they combine and the three molecules are compressed to the volume of two by the force of chemical attraction, the hydrogen suffers most because the oxygen has sixteen times its specific gravity, so that the water globule should be represented as a hemisphere of oxygen with two quarter spheres of hydrogen above it. The effect then of an electrolytic strain would be to push the hydrogen molecules one way and the oxygen the opposite and to change the water from a fluid in which all the molecules stood perpendicularly to one in which they leant diagonally: and this is what gives the distortion which produces double refraction in the water electrolyte.

The refraction change in glass under "severe stress" is due to a similar change, but owing to the greater cohesion of the solid molecules is much more difficult to bring about than in water, and the relief for the same reason is slow. No doubt repetition of the stress and its relief would soon make the glass rotten.

A great deal is made of the Zeeman effect as confirming the electron theory. But it is only a strain produced by a strong current with distortion of molecules and consequent polarization of light: and it is of no more significance than the same effect in the liquid electrolyte. In fact it is another philosopher's mare's nest.

Influence, then, is a vibration of the æther: produced by the electromotion of molecules: producing electricity in molecules: producing it of the same sort as the electricity that sent out the influence vibrations: and therefore there are two æther waves of influence, a positive electricity producing wave, and a negative electricity producing wave.

ELECTRICITY

CHAPTER XXIX

TWO ELECTRICITIES

ELECTROMOTIVE force is a vibration acting on the molecules of compound liquids and gases, and reproduced by their reversion to the state from which its action changed them. It cannot therefore be a vibration of material and must be a vibration of the æther associated with the material. The vibration changes the material: the reversion of the material reproduces the vibration. It is the æther that vibrates: not the material. The material is fastened to its place; the æther vibration radiates free.

When an ocean wave, half a mile long and thirty feet high, approaches a motionless ship, it first draws the ship towards it, tilting it at the same time in the direction in which the wave is going; then it drops it back almost to the same place as at first it occupied, at the same time tilting it away from the departing wave; and if two or more ships were side by side and broadside on to the wave, they would be considerably jostled together. Now the molecules of liquid air, which we suppose are assembled in groups, assume a position with respect to each other similar to that of the ships at rest, because in all of them the heavier oxygen must hold the lower place: so, though we do not know how the induction or electromotive æther waves act on the molecules, it appears probable that they act in a manner comparable to that of the ocean wave on the ships. And compared with the molecule these waves are immensely greater than the sea wave compared with the ships, and also immensely more swift and frequent.

And if the oxygen molecules are violently tilted against and entangled with the nitrogen of the next group, and this happens all along any ordinary conducting line practically at the same instant owing to the extreme velocity of the wave motion, and recurs with every wave: then we can understand how a current of electricity is established, with a continued movement of oxygen molecules in one direction and of nitrogen in the other.

Now what is called influence produces a separation of the particles of molecular groups, the force acting in every way the same as the electromotive æther wave. For we find that there is the production of strain and of action by both, and they neither of them do more than this. We have seen the effect of influence on conductors, though not as yet any special examples which we can say are parallel to the effect of the spark in air, and in fact influence only begins that action and has not the power to finish it. Still so far as it goes the action is similar. The electromotive force puts a strain on the electrolyte and if it is strong enough, causes complete electrolytic movement and conduction; the influence wave causes a strain in the electrolyte, but can do no more.

With a small voltaic battery we cannot produce but a tiny spark in air, but if a spark discharge is being made near at hand, the battery can discharge a spark half an inch or more in length. Plainly the electrolytically inclined air is put under a further strain to electrolysis by the influence waves from the spark discharge, and this helps the discharge of the battery. And again, when a body is charged, the electricity it receives is certainly given by the action of the electromotive force, and as certainly that body then sends out influence waves that give electricity to other electrolytes, thus again indicating that the electromotive force and the influence wave are identical.

"Electromotive force is that which moves electricity."

It is often difficult to follow up the meaning of anagrammatic sentences such as this, they may mean what we mean, and again they may not. Most scientists seem to include both current and electromotive force under the term electricity, and as we have done so up to this, we will continue to use electricity as meaning the whole effect: current as specially meaning the action of the electrolyte whether gas, solution, or liquid air .coating: and electromotive force as the wave of motion that propagates the excitation started at the place of manufacture of the electricity.

Whatever the electromotive force may be, it is not a wave of the material of the electrolyte, whether that be gas, the fluid in a cell, or the fluid on a wire. It is no vibration of molecules, and has as little to do with them as the sound of a bell has to do with the bell and bell-clapper that produced it, or the air it moves, or the ears and nerves it acts on. A force is movement, and movement is not material. However much the bell may waver after the blow of the clapper, it is not because the clapper has put some fresh material into it, but because it has transferred motion to the bell. Experiment has shown that the electromotive force can pass through material at the rate of twenty-four thousand miles in a second, and experience has also shown that any movement of molecules to even a two thousandth part of the distance in the same time will dissipate them by heat in a moment. So we may safely believe that the electromotive force is an æther wave, and that it is carried by the æther associated with the molecules of its vehicle.

Why the wave of electromotive force prefers to keep to the æther associated with fluids, is because they are compound substances, and because in them electrolysis is more easily started than in gases or solids. Other waves also have their preferences: the sound wave prefers to use

the air, and heat waves prefer solids: and all for the same reason, that they can act on them more easily than on other substances.

Electricity is often said to be like heat and they are alike in some things, but in others utterly different. Both of them are an interaction between vibrating æther and molecules. The æther waves of radiant heat, acting in some way on the molecule, cause it to change, and so also the electromotive æther wave produces a change in the molecule. The molecule in reaction from heat may reproduce heat waves or others of higher rate of vibration, and the molecule in reaction from electricity may reproduce electromotive or other waves.

Between bodies equally heated no heat can pass, and "between places of the same potential no current will flow." When a substance is acted on by heat, its molecules expand, and so long as it is in contact with no colder substance, they remain expanded although they must be under a strain to get rid of the expansion. When a substance is acted on by electricity something happens to its molecules which puts them under a strain, and so long as they are out of connection with differently strained bodies they retain the strain or lose it very slowly by influence.

Beyond this there is no comparison between heat and electricity. Heat results from the contraction of molecules, electricity from their percussion. The conduction of heat is slow, while that of electricity is instantaneous. Induction of heat is slow, of electricity quick. Heat will invade solids easily and liquids with difficulty, electricity uses liquids but can make no use of solids. Heat generally produces chemical union, the electric wave causes disunion.

What is chemical union? The cohesion of molecules. The junction of the outer surfaces of molecules according to some particular shapings of the molecules: a conjunction in which the molecules are not destroyed by intermixture,

but merely associated by contact. A meeting of exterior surfaces only. Heat we believe to be an expansion of the molecule caused by vibrations of æther acting from within: electricity is evidently an action of the vibrations of æther acting outside the molecules and caused by the coming together of their surfaces.

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Are there two electricities or only one ?

In induction there must be two sorts of vibrations as there are two effects: whether the induction wave is positive or negative it can be polarized: they act differently, the one wave acting to carry the nitrogen molecules with it, and the other to carry the oxygen: the one acts on the basic molecule only and the other on the acid: the one to act on the molecule occupying the upper place in the compound molecule and the other to act on those below.

In the voltaic cell there are plainly two effects: the oxygen molecules go to the anode and the hydrogen to the kathode, and to do this there should be two causes. When the oxygen and zinc combine they produce vibrations of electromotive force. Now it is not easy to believe that these vibrations radiate in one direction only: they will if they have a limited channel to work in, such as a conducting wire, be obliged to confine themselves to the channel, but they will radiate in two directions from the point of origin, and if they produce different effects, as is the case, they must be different vibrations: one produced by the zinc, and the other by the oxygen.

If we have an electrical machine placed in front of us so that the earth wire from the cushions is to our left hand and a wire from the conductors to the earth on our right: and if we interrupt the currents in these wires by making them pass through vessels filled with an electrolyte —say solution of sulphate of copper—the effect in both

cases is that the copper is deposited on the right hand electrode in each vessel, precisely as though these represented the anode due to a single current in one direction: or as it might be argued, that the negative and positive vibrations are identical. But the acid in the electrolyte also moves though we may not see it: and the inquiries that we have made oblige us to conclude that there are two opposite currents in the circuit, the one pushing the copper in one direction and the other pushing the oxygen and acid.

If we isolate the machine and put the ends of the wires from the cushions and conductors in Leyden jars, we get the jars charged with two different strains—negative and positive—which can only be due to two different current actions. And here the action is entirely confined to the machine and there are no earth currents to explain away the difference in the charging of the jars.

We can divide the charge in either jar with an empty jar with sparking between the knobs, proving that either strain can produce the full electric effect.

If we put one of our sausage-shaped conductors between the wires of a battery, the current uses it as part of the channel of conduction. If now we remove the negative wire and after that the positive, we find that the conductor has a small charge of positive electricity: and we can give it a small negative charge by removing the positive wire first: no doubt also we would leave it uncharged if we could remove the wires at the same moment, only we can never do this, and we always find one or the other charge on the conductor. The charging of the conductor in any case is due to strain, and it shows that there are two strains, and consequently two movements of electromotive force.

The ends of a voltaic pile are differently electrified, but the middle is neutral. This could not happen if there were not two electricities.

There are stationary waves produced by the interaction of positive and negative induction waves, which confirms the conclusion that the positive and negative electricities are one production, but different motions.

Bruno Kolbe found that a loop of wire, carrying the current between the prime conductors of an influence machine, when tested with a proof electroscope, showed strong excitation near both conductors, positive or negative, and that when the electroscope was pushed further along the wires away from the conductors, the leaves declined until, at a point about halfway, they fell completely together. Professor Trowbridge discovered that "when a long wire is charged, a point in it may be found where a peculiar crackling sound is loudest, and where an exhausted tube lights up, and there are also spaces where the parallel wires, in a long loop, may be connected without impairing the brilliancy of the light in the tube." In both these cases the want of effect was due to the want of electrification on the wire at those points. This is hardly to be explained with one electric wave in one direction, but with two sets of vibrations, not quite in harmony, we should be certain to find that just this interference must happen. The points where the electricity is wanting are the nodes of no action from the effects of the two sets of waves cancelling one another.

Still even with this before him, Kolbe will not allow himself to be moved from the old groove, and says, "there need not necessarily be two electricities. One set of substances may cause right hand spiral currents of electrolysis and another left hand, which coming together would cancel one another." It seems rather an unnecessary complication to introduce supposititious spiral currents, but this is certain, that whatever may be the form of the electromotive waves and the currents that they produce, there is no set of substances which, in electrolysis, produces

only a positive action or a negative, but they all produce both positive and negative, and continue to do so from start to finish, and produce both electricities in equal quantity.

Kolbe also adds, "Therefore both sorts of electricity reside in an uncharged body, and positive electricity is a superfluity and negative a want of electricity in comparison to surroundings. A and B rubbed together, an excess is produced in A and a want in B. Therefore as we can by influence or friction produce an unlimited amount of electricity, we must suppose that some imponderable substance exists in space that makes good the loss in one body—and this can be nothing but æther, which acts as in the case of heat, which continually supplies a body which by conduction loses temperature." He has quite lost himself here. Heat is produced by æther waves: and no body loses heat by conduction unless it is hotter than its neighbours, nor gains heat except from heat vibrations. And the substance by which the loss through electric production is made good is the air: no body can be charged if cleared of its air skin and placed in æther, or hydrogen, or even if heated in air: nor will two such cleaned bodies produce any electricity by friction or otherwise.

The æther heat wave, or the æther induction wave, acts upon the molecule, and it, in recovering itself, produces a heat wave, or light wave, or electric wave, as the case may be: there was nothing in the molecule to begin with, and what it produces is a new creation. The molecule cannot create a force: it can only receive a force and be changed by it, and in recovery reproduce an equal force either similar or different from that it received. Electricity is not a residential property but is a product of force, and it does not exist before it is made.

"The oscillations found on discharging a Leyden jar

with a short wire, seem to confirm Franklin's idea that there is but one electricity: + being an excess, and – a deficit of it." We might however equally well say, nullify Franklin's idea, because the excess of motion of the molecules at each swing causes an inversion of the *two* electricities—of the two electromotive forces.

Fill a glass jar to two-thirds of its height with acidulated water, and put it to the same depth in a bowl of acidulated water to which add an earthed wire. Chargê the jar positively for an hour: discharge it and charge it negatively for ten minutes: remove the earthed wire and discharge it again, and then, at short intervals, measure the force and direction of the current produced by the residuary strain left in the glass of the jar. It will be at first negative, then declining in force it will disappear and change to positive. There have evidently been two strains produced in the glass. Now two similarly consecutively recovering strains can be produced in material by mechanical force: but it needs to be done by two different forces.

Most persons say that there is only one sort of electricity, and every one speaks of two, but surely we have now assembled sufficient facts upon which to base an opinion as to whether one or other or neither are right.

What then is electricity? What is the impression that the studies we have undertaken has made upon you? The following is surely your united decision.

Electricity is vibration of the æther that is associated with the surfaces of conjoining molecules. Produced by conjunction of molecules: transmitted with conjunction of molecules: and consisting of two currents, the directions of which depend on the position and relation to one another of the conjoining molecules. And as there are two vibrations and two currents, there are two electricities.

(Conjunction of molecules, that is the drawing together

of molecules by gravitation, produces electricity, but only under certain conditions. The force of the gravitation must be comparatively feeble. Chemical conjunction produces electricity only when it acts mildly: violent chemical union produces not electricity, but the more rapid vibrations of heat, light, and actinism.)

RAYS

CHAPTER XXX

THE RAY DESCRIBED

Is it necessary to explain what is meant by a ray? When we see a picture of a saint with beams streaming from his head, we understand that they represent, not fixed material ornaments or puffs of vapour, but light which is constantly produced and sent forth by some property of the saintly one's head, from which it streams away in straight lines never to return. The painted streaks are intended to be taken for beams of light, and beams of light are radiant lines of æther vibrations that illumine material.

But besides these light rays there are other rays which have no light-giving power. "The carbon arc light—when unshaded—scorches and blisters the skin and produces active inflammation of the eyes even when protected by double thick grey glasses which remove all the dazzling effects of light." The harm is done by the actinic æther rays which cause chemical decomposition, and which cannot be cut off by grey glass, but can be cut off, that is changed, by other mediums.

The rays produced by heated bodies are another set of æther vibrations and are not streams of material.

And the rays of influence produced by electrochemical means are also lines of radiant æther vibrations, and it is about them that we are now inquiring, and some are made visible and others not.

A ray, however it may have been produced or whatever effect it may produce, is a wave motion in the æther and

not any movement of material more substantial than the æther.

Rays are æther vibrations that flow in straight unbending lines, and physically we know nothing of a light ray unless it directly enters our eyes. We see none of the rays of the sun unless we foolishly look straight at it, but only their reflection or reproduction by material substances: the course of a ray of light is only revealed to us by its action on substantial material such as dust or vapour: it is not reflected by the gases of the air. It would be easy to arrange to send a beam from a brilliant lamp through a darkened room, in such a way that the beam should not play on any part of the walls of the room, and that beam would be invisible to any one in the room which would appear to him to be absolutely dark: and if a puff of smoke were sent into that beam, the room would be immediately lighted up by the reflected rays from the particles of the smoke.

But because actinic rays can act on the gases of air a photographic film could be darkened in that dark room by invisible reflected actinic rays.

No particles enter our eyes or act on the photographic plate, but only vibrations of æther. The ray is not the material acted on, but the æther vibrations that act. Action and production are reciprocal: a ray acts on a molecule of matter which in recovery produces a ray to act elsewhere.

According to the theory of the conservation of energy, the ray cannot be lost: but against this we have the action of inertia: the ray must lose some energy in every encounter with inertia which is a non-reproductive force, so the ray should at last be worn out and the energy lost.

Very many ray-producing experiments have been made, but most of them with the idea of finding new varieties of rays, rather than for any examination of the rays

themselves, or of their mode of action. The experiments have therefore been made in as complicated a manner as possible by varying intermixtures of chemical, mechanical, electrical and magnetic devices, all worked together like the mess in a conjurer's hat, with the result, that this region of what is called electrical rays is a true country of the *coquecigrues*, in which every thing is made to appear something that it truly is not. The language in which most of these experiments is described is what to an ordinary outsider is a stumbling-block and foolishness: some have been very carelessly described, and some are contradictory: but we must look away when Jove nods. They are the material we have to examine, and we must do the best we can with them.

What we have to do then is to puzzle out the interpretation of these experiments, and it must be the true one. For want of the *true* interpretation of a Hebrew text, Moses has been represented as wearing horns instead of rays on his forehead, and so is made to appear more in what we have been brought up to consider a likeness to Satan, than what we should expect to be that of the great Israelitish high priest and leader. Misrepresentation of the ray experiments has in like manner led to an indiscrimination of matter and motion similar to that of Moses' head ornaments. We must therefore take great pains in interpreting the effect of the manipulations that produce the rays, and the causes that lead to the production of the rays, and the action of the rays after their production: but in this last it will not be necessary to push inquiry further than to show whether, what are called rays, are in reality æther vibrations, or in reality moving material, for the mistaking of one for the other is a common occurrence. One thing we must always bear in mind, and that is that a real ray is a set of vibrations of æther, and not any movement of material, and we must reject any

interpretation, however pretty and plausible, that violates this rule. No puff of air, or squirt of water, or rush of particles however small they may be, is a ray.

Every æther ray has its definite rate of vibrations which remains unchanged in length and frequency however strong or weak they may be: and because the æther has no friction the rays remain unchanged however far they may go, at any rate for such short distances as our sun's—more force would be felt near the sun because more waves would be encountered there, but not more force in each wave.

The sun's material sends out impulses that produce radiant vibrations in the æther: each contraction of a molecule on the sun sends out one impulse through the æther: and a number of such vibrations following one another is a ray.

The effect of an æther heat vibration on a molecule is to expand it, and the force of vibration being changed to work of expansion, the vibration ceases and the æther is at rest. The molecule being under pressure from gravitation is restored to its former size, and in being so restored reproduces an equivalent vibration in the æther to that which expanded it.

The effect produced upon the molecule by the vibration rests in part with the rate of the vibration and in part with the material and the work it allows the vibration to do in it: and when the molecule subsequently produces a wave in the æther, it entirely depends on the material what sort this new vibration may be.

We call those rays that include a certain octave of vibrations, rays of light, because we see them produce light by acting on material, but it is certain that material acted on by other rays beyond the light octave, does, on occasion, produce rays of a frequency belonging to the

light rays, and the new ray is due entirely to the action of the material.

Each set of rays has been named from the principal effect that it produces on material, and we name those electrical that have been produced by and reproduce electricity: but just as all the others have no heat, or light, or actinism in themselves, but merely produce effects in substances that they excite by their vibrations, and that these excited substances in their turn may generally reproduce the same sort of rays: so the electrical rays have no electricity in them, but merely a very distinct set of æther vibrations, which are very long, and slow in recurrence compared with the other æther vibrations, and which principally produce electricity on the substances on which they act: and the substances acted on may principally produce these long vibrations, but may also produce in reaction the vibrations associated with heat, light, or actinism.

When an electric spark is made in air, it is the result of the electromotive force breaking down the resistance of the air to electrolysis: and except for accidents it follows a direct line between the electrodes. Examination of the spark with the revolving mirror shows that it is not a continuous flame but a multitude of small sparks. The little groups of oxygen and nitrogen are shaken apart by the electromotive wave, and then combining chemically burn violently. They are drawn together by cohesion and combine with concussion, thus reproducing the electromotive waves which follow the line of the spark, but they also produce some electromotive waves radiating at right angles to the spark line and these are induction rays. The heat, and light, and actinic rays of the spark have nothing to do with the electric induction rays: they occur because the compound gas resulting from the combination of the gases of air is a third more dense than air, and because

the contraction of its molecules throws the æther associated with them into vibrations that produce these various rays. Among all the rays produced it is the induction rays only that can be called electric rays emitted by the spark.

Like all other rays of æther vibrations, these influence rays have no more than a mechanical effect, but the effect is in the main such as is sufficient to give the molecule acted on a tendency to reproduce the same action that started the wave: and that action is chemical combination. The following are some examples.

A spark gap breaks down more easily when a spark is discharged in its neighbourhood because of the action of the induction æther waves on the air in the gap: which air is affected in precisely the same way when it is exposed to rays of ultra-violet light, or of X rays, or any other actinic rays, because in all these cases, inductive or otherwise, the molecules are given a tendency to chemical combination.

If the ends of the wires from a Leyden jar are put near each other, but not so close as to discharge the jar, and another jar, near at hand, is discharged with a spark, the first jar will also be discharged because the æther vibrations set up by the discharge of the other jar, have brought the air to a state in which it is more easily forced into electrolytic action than it was before.

In that small arrangement called a coherer, which is a glass tube with some loose filings in it, and which is used in aerial telegraphy, the "heap of filings scarcely conducts at all for want of cohesion among their coatings of condensed air. But conducts instantly if a spark occurs within a few yards. The resisting films of air are broken down by minute internal discharges in the powder. A tap restores its nonconductiveness." Each filing has its coat of condensed air, and each coat has its covering film which

prevents the coats from mingling: and the films are broken down by the ray of æther vibrations sent out by the spark, and not by "minute internal discharges," and the coats then mingle and form a continuous conductor with uninterrupted electrolytic action.

We have had several times in other chapters besides this to refer to the liquid air coating which probably is adherent to all exposed surfaces; in fact in our study this coating has bulked largely; but it may be that the fact, that the air coating has a containing skin, requires some confirmation in the minds of those who have not had its reality made clear to them by experiment. There is probably no scientist who does not recognize the existence of both the liquid air coating and its skin, but these have by most of them been persistently ignored, as they are stumbling-blocks to advanced ideas and have a rudely toxic effect on electrons and such like metaphysic nonentities. And because the scientist ignores them, the reviewer knows them not, and we see nothing about their beauties in the magazine articles written to instruct the public.

Both the condensed air coat and its skin are beyond microscopic examination, but condensed air is a liquid, and we can easily show that another liquid, that is water, has a skin.

There is a beautiful experiment that shows the existence of the skin on water. The experiment is this. Put two straight taps in the side of a cistern, one directly below the other: the jets of water flowing from these taps will fall in two different curves, and because the lower jet goes further in a horizontal direction, the upper jet impinges on it: it does not however join the lower jet but bounds off it: their skins have prevented their joining. Now if a stick of sealing-wax is electrified by rubbing even at five feet away, the jets immediately join: because the rays

of influence sent out by the wax have broken up the cohesion of the molecules of the water-skins.

We can see the skin on water. If we pour some water into a tumbler and put a spoon in it, and look up from one side into the water, we shall see the under surface of the water-skin shining like the brightest silver, and it is perfectly opaque to sight: and the reflection of the immersed part of the spoon is on this underside, and the part of the spoon out of the water we cannot see. It is plain that this points to a difference of shape of the surface molecules to those which are under them. The surface molecule has the same quantity of cohesive attraction towards its own centre and towards its fellow molecules as any others have, but while those in the body of the water are surrounded on all sides by equally dense molecules, the surface molecule has only air above it, which has little attraction for it, and from losing attraction above it has some of its own central attraction to spare, and for both of these reasons its upper side is flattened. The water surface therefore is composed, probably, of flattened molecules approaching a platino-convex shape with hexagonal outline, which cling together more strongly than those of the rest of the water and so form a slightly toughened skin.

It is this skin, assisted by intercohesion of the molecules, that keeps raindrops and other drops in their spherical form. Without the skin the drops in falling would at once break up. Chemists, when they wish to add a liquid drop by drop, use a tube with one end drawn out to a fine point and with a hole in it, and if water be dropped from such a tube it forms in globes round the point: now if a stick of sealing-wax be excited near at hand its influence vibrations shatter the skin of the drop, and the water then falls in a tiny thread the size of the aperture in the glass—the molecules are now only kept together by cohesion

and the thread of water is soon broken up by its acceleration of fall due to gravity.

It is reasonable to suppose that all fluid surface molecules are flattened by their own cohesion when they are in contact with less dense surfaces, and that the same distortion happens when they meet denser surfaces on account of the increased mutual cohesive force which the contact occasions, and that it is on this account that they so obstinately adhere to such surfaces and cannot be separated from them except by heat or substitution, and in some cases perhaps not entirely by these.

RAYS

CHAPTER XXXI

HERTZIAN RAYS

We will now consider the Hertzian ray, which is composed of induction waves intensified by oscillation. These rays have been mixed up with light rays, magnetic attraction, X-rays, and electrolysis in gases, into a huge mountain of puzzle, and it has brought forth that "ridiculus mus" electron, a puny reversion to the emission of the ancients.

The Hertzian wave is not a wave of electricity. Mr. Larmor says "the transmission of Hertzian waves through pipes is a proof that they are not in any way electrical," and "they stand in the same relation to electricity that radiant heat does to heat contained in matter." Both the radiant heat ray and the radiant Hertzian ray are vibrations of æther and nothing more.

The Hertzian wave is produced by the electric spark, and for a continuance of the ray the spark must be continuously renewed. This may be done, as Hertz did it, with an oscillating spark, or by blowing across a gap, or in other ways, and that seemingly preferred for wireless telegraphy is the ball oscillator of Righi, the more intense action of which has made it possible to produce induction vibrations sufficiently ample to carry across the Atlantic under favourable circumstances.

The Hertzian ray owing to the oscillation of the spark is much more penetrating than the ordinary induction ray which can be stopped by a plate of metal, or even by a sheet of wire-netting, and any object surrounded with wire gauze is quite beyond their influence: but the Hertzian

waves are with great difficulty prevented from access, as they pass through the smallest crevice.

Hertz produced these waves in quantity and continuously by sending the discharge of an induction coil through an apparatus that he invented. This consists of two conductors with a spark gap between. A convenient form is two sheets of metal plate, fifteen inches square, about a foot apart, upright and in a line with one another, and each with a six-inch wire attached to the near side, and ending in polished brass balls that nearly touch. This Hertz called an oscillator from its action on the spark. When the plates are sufficiently charged, the electricity breaks down the air gap, and leaping across surcharges the other plate: from this it is sent back again, and so by continued crossing and recrossing a succession of sparks is kept up with a rapidity of many millions in a second.

These sparks produce induction waves in the æther: and the length of the wave produced depends on the number of sparks in a second: and this number depends on the size of the apparatus. In such an apparatus as that here described, there would be about a hundred million sparks in a second, and the length of the induced wave would be about ten feet. As their rate of transmission through the æther is the same as that of every other æther wave, that is to say about 186,000 miles in a second, if either their length is known, or their number in a second, the other measure can be found by dividing the equivalent of 186,000 miles in feet by the known number.

To detect the waves Hertz used a wire bent into a ring with the ends nearly touching, and he named it a resonator. When of the right size and held in the proper position, electricity is produced on the ring by the induction waves, and sparks pass between the wire ends. Hertz had a large sheet of metal set up at the end of his room to reflect the waves, and by exploring with the resonator found

nodal points of no vibration caused by the interference of the direct and reflected waves: and the distance between these nodes was half a wave length.

The waves can only be detected by the resonator when it is held horizontally in the plane that passes at right angles through the surfaces of the plates and through their spark gap: and if held vertically to this plane it is not acted on by the vibrations as they are polarized in this plane. Wood has been found to have a selective absorption for the vibrations according to the direction of its grain, and they can be refracted by a prism of pitch. So we see that these rays can be reflected, and refracted, and diffracted, and in fact acted on in every way like other æther rays, and that they therefore differ in no way from the others except in their scales of length and frequency. They are not electricity, but produce it on suitable material, and in this action also they resemble other rays in that some of their energy is always wasted even when the material is the most suitable.

The Hertzian wave, like all other waves, radiates in straight lines from its point of origin, but it differs from most other æther waves in this, that the others spread in every direction, while these are polarized in the plane that was before mentioned, and spread in rings more or less confined to that plane. And probably it is this difference between them and ordinary induction waves which are not polarized that makes the latter so very much weaker. That the rays are thus polarized is sufficiently proved by Hertz's experiments, but this point has been the subject of special examination which has confirmed the statement.

These rays, owing to the great length of the vibrations have great penetrative power in the case of material on which they have no action, but they act on metals, that is, in their air skins and are stopped by them: and like all

16

rays the further they go the weaker they become: and those passing through air no doubt encounter material on which they can act and waste their vibrations. So the rays produced by Hertz's oscillator, not being originated by any very strong force, do not carry far, about a hundred feet being the limit so far obtained, and that with the aid of a reflector.

Those rays which also are called Hertzian though not produced directly by the electric spark and which are used by Marconi in wireless telegraphy, are the longest æther waves known, those preferred for use being about six hundred feet long, but they can be made much longer by retarding the oscillations and much shorter by hastening them, and the smallest yet produced have been made with Righi's machine, in which the central spark acts in oil, and from which waves a quarter of an inch long can be sent out.

The Marconi waves, being produced by a very much larger instrument than the Hertz oscillator, have an amplitude that carries them much further. You will find published descriptions of the instrument if you wish to study them, but it would be much better to see the instrument. The author has not seen an instrument and does not care to describe what he has not seen: and as for the descriptions that he has read, they do not appear to him to err on the side of lucidity.

Apparently the main principle that is relied on, by the manufacturers of the machines, to give success in aerial telegraphy, is, that the more means you employ for doing anything the more will be the result: oscillating discharges are sent through many long wires arranged on frames at the station, and their combined energy produces induction waves of great amplitude and therefore of great carrying power: and attempts at increase of power seem to take the line of increase in the number of wires, though one would

think that several other expedients might be tried, and one might make some conjectural remarks about this.

We know that induction waves are projected at right angles to the surfaces producing them; and that the Marconi waves being induction waves, they are not made by the alternating currents running along the wires, but by the chemical combination of the molecules on the surfaces of the wires which is set up by the electrolytic action of the currents: and that the vibrations thus produced in the æther are sent out by the wires, in consequence of the shape of their surfaces, in all directions in the plane at right angles to the wires. Now one would suppose therefore, that if a sheet of metal were used, and had the currents run on to it from a multitude of points, so that the whole surface was brought into action, that the effect would not only be very much stronger than with the wires, but that also the direction of the radiation could be controlled, in the same way that the direction of the current is controlled, by a disc-shaped anode in electrical experiments.

These long waves from the wires can be refracted and reflected like the waves of heat and light, but with more difficulty, as they have more penetrative power than the shorter waves owing to their much greater size in comparison with the molecule, which they can pass without being broken up, that is absorbed or reflected. Just in the same way that a great sea wave will pass a boat, while ripples that encounter it are broken up or reflected. "Sulphur is opaque to light because it is composed of minute separate crystals whose facets reflect light like powdered glass, but is transparent to Hertzian waves as the crystals are very small to the wave of that length. So the substance as regards these radiations may be considered homogeneous." This is Maxwell's explanation and it appears to be universally accepted.

But the elementary molecules are all less than a twenty-five millionth of an inch in diameter, and the average wave of light is about a twenty-five thousandth of an inch long. Why then do not the rays of light penetrate all elementary substances? Surely a thousand times the breadth of the molecule should suffice if length of wave is the only necessity. And yet the light rays penetrate glass which is a mixture of large compound molecules, and will not pass through iron with its small, simple molecules. Cast-iron is decidedly crystalline, and so are many transparent and opaque crystals of elements and of compound salts: so the crystalline formation does not seem to be the bar to transparency that Maxwell assumes it to be, nor is length of wave the only reason for penetration of rays.

"Marconi signals could be read at 3,800 kilometres by night, but only 1,300 by day." There is evidently a lessening of propulsive force by day, that is a decrease in the amplitude of the waves, so it is probable that the falling off occurs at the wires. They might through the heat of the day become less tense: would this affect the emission of waves of æther? But this is guessing: and Marconi has suggested that "the sunlight disperses the negative charge on the antennæ," that is dries off some of the liquid air on the wires.

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It is somewhat the fashion now in England, though not on the Continent, to call all sorts of rays light rays. There is no reason nor advantage so far as one can see in doing this any more than there would be in calling them all actinic, or heat, or electrical rays. A wolf met a pig and would have killed it, but the pig said, "This is Friday, and flesh is forbidden on Friday." So the wolf drew back and said, "Ah yes, well goodbye, Mr. Whatsyourname,"

and all would have been well but for the silly vanity of the pig, who would go on talking. "I am called," said he, "by many names: swine, pig, grunter, and the Latins call me porcus." "Porpoise!" said the wolf; "why that is as good as fish!" So he fell on him and ate him. We will not worry about the moral of this, but it is surely better not to use words that do not apply. Most wheels have radiant spokes, but because cart-wheels have wooden spokes is no reason for calling the spokes of iron wheels, wood spokes: and similarly it seems silly to couple the terms, light and optics, with rays which give no light and do not affect our optics.

RAYS

CHAPTER XXXII

RÖNTGEN AND OTHER RAYS

We will now consider some other rays.

When electricity is sent through a glass tube from which air is being exhausted, it at first passes in sparks: then when the molecules are brought by further relief of pressure into a condition in which they are more ready to combine, the electrolytic track of the current is shown along the axis of the tube by a thin flexible red line: and with more exhaustion and fewer molecules, the whole tube between the electrodes is in action and filled with a glow. So far as this the exhaustion has aided the combination of the molecules, and the light produced by the red line and the glow has been that of the longer red rays because of the less amount of energy required for the combination: but beyond this point the rays given off incline to blue, and this is on account of the more violent contraction that the expanded molecules suffer in combining and the sharper vibrations thus imparted to the æther.

The waves called electrical, that is the conduction and induction æther waves, when acting on material can produce no other ray than the electrical, unless the material changes the waves through changes in itself: it is not these waves that give the light to the spark, or the effect on a photographic plate, or heat, but the reaction of the molecules after being acted on by these waves. In his chart of vibrations Professor Lebedeff shows an unexplored interval between the shortest of the electrical waves and the longest of the heat waves: and if, as we suppose, the electrical

waves are due to molecular action on the æther outside the molecules, and the waves of heat, light, and actinism, to action on the æther within the molecules, it is probable that the region will always remain a blank.

"When the termini of an excited Ruhmkorff coil are in an exhausted tube, the tube is filled with luminosity, and rays can be seen streaming from the kathode. The rays do not seek the anode. Professor Crookes believes that the impact of the molecules of the remaining gas, on the phosphorescent substance, produces light."

There are in this instance emissions of rays from two sources: one the stream from the kathode, and the other from the surface of the glass tube.

The molecular stream of electrolytic conduction from the kathode need not directly seek the anode, and by varying the shape of the kathode it may be projected in different directions. When the kathode is made in the shape of a flat plate, the stream is projected at right angles from the face of the plate, and does not swerve from that line. Lenard, hearing from Hertz that this stream could pass through aluminium foil, put a small window of aluminium a ten thousandth of an inch thick in the end of a tube, and found that the kathode stream passed through it and into the air outside for a distance of nearly an inch. The phenomena inside the tube is called kathode rays, and that outside Lenard rays: they can both be deflected by a magnet: both excite luminescence: affect a photographic plate: pass through aluminium a hundredth of an inch thick and through very thin copper: and discharge an electroscope. They are both one and the same—not rays at all, but moving oxygen molecules.

This stream of oxygen molecules is more noticable than that of the nitrogen molecules which moves in the opposite direction, because the four nitrogen units receive

among them only the same amount of impetus as is given to one oxygen; but nevertheless they do produce, by their condensation on the kathode, a feeble light as we shall presently see.

It is on account of this difference of impetus that a similar action has been noticed when a flame is placed between two oppositely electrified conductors. They set up an electrolytic action in the flame which distorts it into two wings inclined towards the electrodes, one round and full but not much advanced towards the kathode, and the other longer and pointed towards the anode: the first caused by the ample flow of nitrogen and the other by the stronger rush of oxygen.

This sort of thing can also be made to occur in electrolytic solutions, where with a strong discharge through good conducting fluid, the liquid creeps from the kathode to the anode, that is to say the dense oxygen has received enough impetus to carry the fluid with it against the opposite movement of the hydrogen, although this has twice as many molecules. This is an effect that is not seen in badly conducting liquids in which most of the energy of the current is wasted in overcoming resistance to change.

The mechanical movement of this material oxygen stream has been shown by Professor Crookes by means of a tube in which a paddle-wheel is made to run along rails by the impact of the oxygen molecules on those of its paddles that are uppermost and in the stream.

The oxygen molecules in tubes always leave the surface of the kathode at a right angle to it, so they can be focussed as though they were a ray by a saucer-shaped kathode, and a scrap of platinum placed at their point of meeting in the focus of the saucer may be made red-hot: the crowding together of the molecules causes their action to be much slower and more like ordinary open air

condensation, and consequently when they are thus crowded there are more heat vibrations sent out and fewer light vibrations.

The kathode stream is no ray but a stream of material, and the pale rays of light that come from this stream in the tube are due to the electrolytic combination of molecules of oxygen with nitrogen and metallic vapours.

When the oxygen molecules are discharged against Lenard's little window, they condense to liquid on impact with the aluminium, pass through, and expand to gas on the other side: and they are probably assisted in their forward movement by the impetus of successive batches of molecules. The stream passes through the aluminium because it is porous: it leaks through between the aluminium molecules and does not pass through them as rays do. The much thinner film of a soap bubble stops the stream because the bubble is not porous: and the stream is quickly lost in air with which its molecules mix, restored to their natural gaseous state. Lenard let the stream "from the aluminium window pass into a tube five feet long which was exhausted as much as possible. It passed in straight lines along the tube and could be detected at the end. He says therefore that the æther is their medium." If a little tobacco smoke had been shot into the tube it would have behaved in the same way: but would the æther have been the medium of the tobacco smoke?

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The other rays that come from Crookes' tube have always been confounded with the kathode stream of oxygen molecules, but they are true rays and are due to the condensation of the oxygen molecules on the glass of the tube. The kathode stream that produces this light can be turned about by a magnet because it is a stream of molecules of oxygen, but the light rays that leave the glass are not

thus acted on, being æther waves. The molecules of the oxygen stream are expanded by the rarefaction of the tube and contract so violently on becoming liquid when they condense on the glass, that they can produce only those vibrations that belong to the ultra-violet and luminous rays: they can therefore strongly excite phosphorescence in suitable substances and do not excite much heat. These are true rays, but they come neither from kathode nor anode, but from the surface of the glass of the tube.

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There is a limit of exhaustion beyond which conduction ceases, and we might almost be inclined to say that it was because of the separation of the molecules, but this probably never happens, the molecules expand and fill all the space as bubbles would do, and the reason for their no longer conducting by electrolysis is that the electromotive wave is too weak to impel the enlarged molecules across the increased distances occupied by them. The cessation is certainly not due to want of gas, for just before conduction stops there is still a considerable stream of oxygen molecules impinging on the glass, and the removal of a few more atmospheres pressure could not empty the tube; and as to any of the theories of separation of molecules, they are all based upon mechanically impossible forces, and on movements that could not effect the separation, there is therefore no explanation that satisfies the conditions except that given above.

When the exhaustion is pushed almost to the point of nonconduction a ray is given out that was discovered by Professor Röntgen and named by him the X ray. These rays penetrate substances that are opaque to ordinary light, the depth to which they can go depending principally on the density of the substance, for which reason metals are very opaque to them, and uranium the densest of metals,

the most opaque: they penetrate below the surface into all substances, and on account of this penetration they cannot be reflected or refracted but are diffused. Neither can they be polarized which is obvious, but also no sign of interference has been discovered, the reason for which is not at all so obvious. Being thus prevented from acting like ordinary light, the measure of their vibrations has not yet been found, but from the manner in which they are produced by the exaggerated force of condensation of the molecules, it is certain that their vibrations are smaller than those of the ultra-violet found in the solar spectrum.

All this points to some peculiarity in the production of these waves, and their subsequent action would in every way be accounted for if the following theory were allowed: which is that the rays are produced by single molecules condensing separately on the glass and each producing a single light vibration.

It is only when the tube is about to become nonconductive that the X rays can be formed, which, according to our ideas, is when the molecules are moved with difficulty in electrolysis: when the oxygen molecules are at such a distance from one another that they must condense separately on the glass and produce single vibrations: and when on contracting in condensation they must, owing to their liberty from much of their intercohesion, produce the greatest effect on the æther by their simultaneous concussion of impact and condensation on the glass. The want of interference and impossibility of polarization of X rays directly point to such a single wave.

"Goldhammer says that they are very small waves of ultra-violet light," and "waves very small in comparison with surface particles would refuse reflection or polarization," but it is their *penetration* owing to their smallness that occasions this refusal. "Jaumann thinks that they are longitudinal light-rays," but this is pure guesswork

unsupported by any fact, and it is difficult to understand how an exciting particle can produce any but an ordinary vibration.

Röntgen rays are actinic but not at all luminous. They act on photographic plates, and all of us have probably seen photographs of our own or some one else's hands, with a light shadow for the flesh, dark shadows for the bones, and perhaps an image of a ring like an ink spot: showing how the density determines the transparency. And this is the usual rule, but the rays in some instances behave in quite an unexpected manner. They will go through "several inches of wood, but are cut off by an ordinary pane of glass," and yet diamond is perfectly transparent to them. We are so accustomed—some of us at any rate—to consider density and hardness as synonymous, that we would at once say that diamond was denser than glass; but density depends on atomic weight and glass is about three times as dense as diamond, and in consequence is more obstructive to these rays, though this does not account for all the difference in their action. Wood being, for the most part, a compound of water and carbon, is but a little more than half as dense as diamond.

The quick diffusion of the Röntgen rays is shown by a precaution that has to be taken in using them for photography. The object must be put close to the photographic plate: even then a ring or other such opaque object, shows the diffusion of the rays by the haziness of the edges of its picture. High electromotive force is always needed for good work because without strong force the action does not reach the point at which these particular rays are propagated.

The density of the glass and the transparency of the diamond teach us one or two things. That transparency to a ray depends on the action of the molecules: that the rays pass through the molecules and do not wriggle through

between them: also that the molecules are all and always in touch except under very extraordinary circumstances, for if this were not the case, all substances would be equally transparent to all rays.

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In the discharge in tubes, the rays made by the kathode stream of oxygen molecules are easily seen even when a small force is employed, but the anode stream of nitrogen, on account of its feebler action, makes hardly any distinguishable ray, and this has led to the belief that there are no positive ions, as they are called. But with certain devices they can be made sufficiently visible, although for the reasons stated, they are always much less noticeable than those of the negatively produced stream.

If a plate with a hole in it is used as kathode, in a moderately exhausted tube, the impetus of the nitrogen molecules from the anode makes them pass backwards through the kathode aperture and they mark their course by sending out a blue ray. If the ordinary imperforate kathode plate is examined it will be seen that the same blue glow of nitrogen radiates from its edges on every side. And the same colour effect is produced if the oxygen stream is directed on a negatively electrified spiral or piece of wire gauze: the oxygen molecules cannot pass through as they are taken up by the wire, but the nitrogen molecules leave the wire and they are recognized by their blue ray. But besides this, if these nitrogen molecules reach the surface of the glass, they produce by their condensation on it, a fluorescence that is weaker than that caused by the oxygen molecules, and which therefore gives a ray with colour tint lower in the spectral scale and easily distinguishable from that made by the condensing oxygen: thus with soda glass, their condensation gives the lower vibrations of a dull orange instead of the higher brilliant

green given by the oxygen. These nitrogen-produced rays are called dia-kathodic, or Goldstein's rays.

Wiedmann's rays are not sufficiently understood to be categorically placed, but they are produced by alternating discharge in a Crookes' tube, and seem to be vagrant Crookes' rays.

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Flammarion says in his book "Thunder and Lightning," that pictures have been imprinted on the skin by some sort of rays emitted by the lightning flash. If these pictures had been printed on the outer dress they would have been somewhat convincing of the idea, but when it comes to a print under a woman's stays or petticoats, it seems more probable that it is due to contusion and not to rays. A wound or a hard blow will often cut off some of the small surface veins from the circulation, and they quickly become black from congealed blood in them and show on the skin like pictures of trees with ramifying branches, and an ordinary bruise may colour the skin, so as to make a patch which a lively imagination might convert into the image of a cow or anything else. Very few persons would have the chance of seeing the mark if it was on a woman's breast or elsewhere, and those who did would make the most of it, and like the story of the three crows, the description would grow from branching lines to a full branched tree, or from a brown patch to a brown cow.

This finishes our examination of the rays that are called electric, and in no case has it seemed necessary to invent any fresh movements, or any weird phrases, or any words more difficult of understanding than electrolysis and contraction: and as these have sufficed to explain every other phase of electricity we ought to be satisfied. Many other rays, which are not our care just now, are originated in various ways, but no doubt have the same proximate

cause as the so-called electric rays, that is to say contraction: for what can radiant light or heat do if it falls on a diamond or some luminous paint, more than by its vibrations expand the molecules in some manner, while their recovery from this excited condition is what causes the æther vibrations that the substance afterwards gives out: and the same must be the answer in every case, radium inclusive: not necessarily a return of the molecules to a former state, but a contraction from some cause.

There is no such thing as a self-illuminating ray. Every ray, every vibration, every movement, is produced through material and reacts on material, and can have no existence without material. Scientists are constantly saying this in one form or another, and as constantly seem to affirm the contrary.

ATMOSPHERIC ELECTRICITY

CHAPTER XXXIII

ATMOSPHERIC ELECTRICITY

WE have so far studied electricity in the laboratory, let us now study its action in nature and see if any of its natural phenomena show any points that disagree with the conclusions that we have arrived at.

They say that there is generally some electricity in the air. "The atmosphere is positively electrified under a clear sky to as much as 1,400 volts per yard in height." The amount given is certainly a maximum, for generally observations show, at the height at which they are usually taken, an amount averaging about four volts positive. Still fourteen hundred have apparently been found and it seems a great deal, but as it requires twenty thousand volts to produce a spark half an inch long, it is nothing compared with the pressure, or tension, or potential, which must be contained in a thunder-cloud: and the tension in the air must at times be even greater than the amount named, so much so that—though very rarely—a flash has come from a blue sky, and an occurrence of this has lately been reported.

The potential increases with height, but less rapidly in the higher air than near the ground, and probably there is none above the limit of cloud.

Not much attention has been given to this subject of atmospheric electricity, and what has been done, has mostly been done with the desire to find out whether such observation would be of use in weather forecasting, it having been supposed that falls of hail, rain, or snow were preceded by negative electrification. But for this purpose

it has been found that the observations are of no value, as forty-five per cent. of the falls come with positive electrification, and in the fifty-five negative cases, the change to negative often comes with the storm, and in both cases, positive and negative, the indications are often remarkable for their want of indication. Besides the changes and intensities are quite local: one place may have a high potential, while another place three miles off may have scarce any: on one side of a town there may be enormous changes of potential from hour to hour and even from minute to minute, while on the other side the record may be a nearly straight line. The utmost, therefore, that can be said is, that "during fine weather the upper air is almost always positive, but during broken weather and after rain it fluctuates, and is more often negative than positive," and that "before and after the passage of a storm-cloud, the air is remarkably free from electricity."

In stormy weather the ordinary induction of the measuring machine is entirely effaced by the action produced by the strongly opposed inductions of the earth and clouds, and the machine usually at such times shows negative electricity, as much as two hundred negative having been recorded: but this cannot be called the electricity of the air, but is the induced electricity of the machine by the influence of the earth or clouds, and the air when tested after the clouds have passed away may be quite free from electricity. During the continuance of a storm the fluctuations are great, sudden, and continuous, and a lightning flash, or a fall of rain often changes the sign, and may for a few moments remove absolutely all sign of electrification.

Observations for electricity in the air must be made in the open: "there is none to be found under trees, in houses, or even in enclosed places such as courts." There

have been many modes used for collecting, such as kites, flags, poles horizontal and upright, pointed rods with a flame or smouldering substance at top, water dropping, and so forth. A simple plan has been described by Mr. C. E. Benham: a calico flag, with hemmed edges, two feet by two and a half, is fastened to a flag pole, the end carrying the flag being separated from the larger piece forming the handle by a rod of vulcanite eight inches long. The flag is put out of an upper window: touched with an earth conductor: and rolled up by means of the handle: then when brought in its electric charge can be measured by an electroscope. The charge on the flag is produced by induced conduction from the earth and not by conduction from the air, and is of the opposite sign to that of the electricity of the air. By rolling up the flag the charge is prevented from escaping, which it otherwise would do from the edges: and as it collects on the outside of the roll, it is much intensified, and its action on the electroscope is so much the stronger, and this must be allowed for if the electricity in the air is to be estimated.

Only a small quantity of electricity can be collected with such small means, but with apparatus sufficiently large, great quantities may be gathered even at ordinary times, and Mr. Crosse, in 1840, had some miles of insulated wire exposed in the air, supported by poles from the tops of the highest trees in his grounds, and with the electricity collected from the air, could produce great sparks twenty times in a minute that exploded with the report of a cannon. When this sort of thing is done the business requires the extremest precautions. Even with a kite and a single wire line "flashes ten feet long and an inch in diameter have been given off from a charged conductor": and Professor Richmann, at St. Petersburgh, was killed in 1753, through going too near his apparatus: the room was wrecked, the doors blown away, and the house

shaken with the discharge. This, however, was a case in which the apparatus was charged by a cloud, as a most terrific peal of thunder *preceded* the flash from the apparatus.

The various methods employed show the electrification at the moment of observation, and as the potential often changes very quickly, may give a quite wrong estimate of the state of the air. To obtain a continuous record Franklin set up an insulated metallic rod at one end of his roof and attached a chime of bells to it which gave notice of the state of the atmospheric electricity, but if a lasting record is wanted, photography must be coupled with some such instrument as the Kelvin water dropper. This instrument is the most approved, but it is clumsy, and where portability is wanted the burning fuse is to be preferred. In either case the original charge carried by the point is carried off by the smoke or dropping water and the electricity of the air substituted, and the deflections of the electrometer needle, connected with the apparatus, measure the potentials at the smoking or dropping point from moment to moment.

It is a pity that observations should have been made only at low altitudes—at least accepted observations—those made on mountain-tops have their own particular conditions, and those made with kites do not seem to be acceptable because they do not show enough electricity in the upper air, and their deficit from what is estimated theoretically is laid down to loss on the way from want of insulation. It is very desirable to find whether there is any electricity in the air above the limit of water vapour, for if there is it can only be due to dust.

There have been one or two theories evolved regarding atmospheric electricity, and all the old books are unanimously agreed in giving evaporation as the cause, and this theory appears to have been proposed and accepted

without any thought of experimental proof. But "atmospheric electricity is not caused by evaporation," for many and exhaustive experiments have since been made to try to prove that evaporation is in some way the cause, because it would so simply explain the presence of electricity in the air and clouds, but every result has only been an added proof that evaporation and electricity have nothing to do with one another. However, it is very probable that "increase of potential is caused by the condensation of water vapour rising from the sea" or from anywhere else. Evaporation is expansion and separation of molecules, neither of which motions can tend to conduction, or convection, or increase of potential, while condensation would certainly increase the potential of acquired electricity.

"Atmospheric electricity is due to condensation of water and to influence of ultra-violet rays": and "atmospheric electricity is not caused by evaporation. But the friction of particles of water, and of dust, cause it." Our present-day philosophers are chary of giving an opinion about this matter, which indeed cannot interest them much: they are not outdoor students, but laboratory essayists, and simple science gives them no pleasure. So we can gain but few ideas regarding the origin of this electricity from books, and the extracts given are all that have been found after some search. Nevertheless, atmospheric electricity is an interesting subject, as it is not an isolated phenomenon, but appears to be the main source of the electricity of the clouds and of all the meteorological occurrences that are connected with them.

Everyone seems agreed that water in some way or other has to do with the electricity in the air, but there are facts that decidedly oppose this idea. Conduction from the atmosphere charges the explorer, but there is always more electricity shown by the instrument when the air is dry, and it appears that moisture is against electrical

intensity, for if we examine the records, we find that the dry and *dusty* times are the most favourable and that the water only comes into play when it is condensing on the dust to form raindrops.

Haze and fog lower the potential because they prevent the dust from rising: clouds lower the potential because they collect the dust to form their charges.

There can be no doubt that the electricity in the air is carried by the dust in the air: there is nothing else in the air that can be charged with electricity.

The earth is constantly at work chemically combining its molecules of materials, and consequently constantly producing electricity. Most of this disappears at once owing to the mutual cancellation of the two unseparated electricities: but on the surface nature may provide means to separate them. The damper parts are the more active chemically, and are the anode in the arrangement, and the dryer parts are the kathode: and the winds can separate the dryer parts and with the buoyant assistance of the water-vapour carry up this positively charged dust, and so leave the earth with an equal negative charge which cannot be cancelled except by a lightning flash, or by rain charged with electricity. "The atmosphere is almost always positive," indeed, the negative electrification of the air in fine weather has been so seldom observed, that we may question whether it may not have been due to some unobserved circumstance other than the natural state of the air that on these few occasions made it so. In stormy weather the fluctuations of the two electricities are plainly due to the counter inductions of earth and cloud, and have no relation to any charges in the air.

At Ithaca, in the United States, there were two observing stations less than a mile apart, at which the records on a fine day were repeatedly found to differ greatly both in potential and in variation. At the lower station the record

would be, for instance, a nearly straight line at 250 volts: while at the upper station it varied between 1,000 and 1,700 volts, with great changes at short intervals. There is no way in which we can account for this, except by supposing that the one station was in a sheltered place where the air was quiet, while the other had stronger winds, from height and exposure, and gusts of dust and smoke.

And there are other instances from which it is evident that it is the dust that carries the electricity, for, independent of any locality, it has been found that strong winds produce strong atmospheric charging, which can only be by raising the dust: that there is less electricity with height because there is less dust: that the air is clear of electricity before and after a storm because the dust has been gathered to the clouds along with the water vapour: and there are no thunderstorms in wet winter but only in dusty summer.

The dust is carried up from the earth by the winds of course, but the upward streams of water-vapour also do some of the work of raising it, and also in some cases, when the vapour is changed to water in globules, some of the work of preventing it from rising, as our fogs disagreeably teach us. According to Quetelet, the air in fine weather is about thirteen times as strongly electrified in winter as it is in summer. This is due, besides the increase of smoke, to the condensation of the water vapour so much more quickly and so much nearer the earth in winter, so that the dust and smoke from winter fires are thus prevented from rising and have to form a denser stratum near the earth. It is the smoke, without doubt, however, that for the most part occasions the increase of electrification recorded in winter, for the observations on which the record is based have been made in populous places and at no great height above the ground: so probably observations made in open country or on a clear hilltop would show that naturally dusty summer had the greater potential.

There are two daily maxima in some places where observations have been made, the first about two hours after sunrise and the other after sunset, the latter being the more marked. Possibly the first represents the warming into activity in dust production of the town fires, and the other the depression of the active dust zone by vapour condensation due to evening cold. In other places there is a single maximum at night.

We see in all the instances we have collected—and they have been made as diverse as possible to illustrate the subject thoroughly—that the electricity is connected with the dust, and not with the water in the air; and that the air has nothing to do with it except as regards a possible action of the ultra-violet sun rays, about which we have no evidence as yet. And with regard to these rays, it is not plain how any action that they could set up, could charge the air with one sort of electricity only: for positive is never produced without an equal quantity of negative, and as there is no apparatus for parting them in the air, they would immediately cancel one another if produced: and also their production is, so far as we know, impossible, as there is no known chemical combination of the air due to these rays. Besides this, there seems to be no other *plausible* idea as to any available source for atmospheric electricity but "induction from the earth," but how the earth should become negatively electrified, whereby alone it could positively induct the air, is a puzzle for which no explanation is offered. In fact, both these theories are merely guesswork, and can stand no examination.

It appears, therefore, that in atmospheric electricity neither the air is charged, nor the water-vapour mixed with the air, but that the excited condition depends on the dust carried by the air and which has become charged by electrolytic action on the surface of the earth.

THE AURORA

CHAPTER XXXIV

DESCRIPTIVE

There have been many theories brought forth regarding the origin of the aurora, and the most distinctly different are given below with the principal objections to them.

The zodiacal light. This at its nearest is two million miles away from the earth, and it is on the daylight side, while auroras occur on the night side.

Ferruginous cosmic dust taking fire as it falls into the atmosphere. Absence of the aurora at the equator is against this.

Light reflected from ice-fields, or from ice particles in the air. As the greater part of the auroral light is not polarized this is impossible.

Phosphorescence or fluorescence of some substance part of the ice particles in the air, the spectrum of the aurora having a bright greenish-yellow line which is not known to belong to any known substance. Neither has such a substance been found in ice.

Electricity, because the auroral light resembles the luminosity produced in rarefied air by the electric current in tubes. Electricity probably has some connection with the aurora, but as the aurora is seen close to the earth the rarefied air of tubes has nothing to do with it.

Streams of positive electricity from the equator, flowing in the upper air like Sowerby's wind currents, and dipping towards the earth at the maximum auroral zone, and creating disturbances with the earth's negative electricity. There are no electrical disturbances associated with the aurora at that zone.

Pressure of the æther. "The sun and the planets are hastening towards Hercules, and the earth describes a spiral ellipse, or to put it better, an elliptic spiral, in which the northern hemisphere always takes the lead: the æther is supposed, therefore, to be compressed at this part and rarefied at the southern hemisphere: and if the condensed æther has positive electrical potential to the rarefied æther, then the north pole will be negatively electrified and the south pole positively, with maximum in September and minimum in March." This is in no way in agreement with the times of the auroras, which have in mean latitudes two maxima, in spring and autumn, verging into one midwinter maximum in high latitudes. And observations of the moon show no sign of condensation or rarefaction of the æther, though her course is at times faster than ours. Also the hastening towards Hercules is mythical and negatived by the spectroscope.

Sun spots, the physicists' universal providers, have, of course, many votaries, and the latest ideas are that the variolated sun either shoots out electrons or a rain of electrified carbon-dust to produce the aurora. These small things surely have not backs broad enough to bear all that is put on them. "The photosphere of the sun contains large quantities of glowing carbon," and "this carbon will emit corpuscles until the resultant charge left on the sun exerts an electrostatic force great enough to prevent further emission: any local elevation of temperature would then cause a stream of corpuscles to leave the sun. When corpuscles pass through gas with high velocity they make it luminous, and Arrhenius has explained many of the periodic peculiarities of the Aurora borealis by the supposition that corpuscles from the sun . . . stream through the upper regions of the atmosphere." He might have added that this also accounts for the dark colour of the Africans who must, near the equator, receive more

pelting from the sooty atoms than we who live further north. But how then would he account for there being no Aurora equatorialis? And as for glowing carbon in the sun, there is none, for carbon is vaporized at half the heat of the sun.

Besides, how could carbon reach us from the sun? The earth could not attract it away from the much more strongly attracting sun, and to suppose that material can be shot clear of the sun's attraction is contrary to evidence. The solar prominences are projected from the sun with such violence that they have been seen to rise with a speed of a hundred and twenty miles in a second, and yet they can get no further from his surface than a few thousand miles, and they are dragged back at the rate of nearly two miles in a second, so strong is the sun's gravitational attraction. It took three years for the earth to draw back to it the dust from Krakatoa, but the sun would clear its atmosphere after the most stupendous eruption in two days at the most. If the sun cannot drive away its lightest material, hydrogen, it certainly cannot drive off its twelve times heavier carbon vapour. Our little earth has sufficient force of gravitation to prevent the escape of our atmosphere, or of anything else leaving us, to far beyond the moon, and we cannot believe that the sun, with many times stronger force, which can control the earth at so many million miles distance, can allow any atom of its substance to leave it.

We will not consider these wild theories, but will gather what evidence we can and try to decide from it, and not make our statement *viva voce* from imagination as those who have formulated the ideas above quoted seem to have done: but the subject is a very difficult one, and we must not be surprised if, after we have finished our search, we are obliged to agree with the final word of the examiner, who asked one of the most stupid of a lot of scholars up

for examination, to explain the aurora. "I knew it yesterday," said the scholar, "but the excitement of the examination has put it out of my head, and I cannot remember it to-day." "That is a pity," said the examiner, "as no one else knows it."

The Royal Society has published the observations made by the officers of the *Discovery*: and M. Angot has written a volume on the Aurora for the International Scientific Series, in which all the latest investigations are mentioned: and from these, and out-of-door personal experiences, which probably many of you have had, we should be able to gather most of the instances that are known about the phenomena. We must go through the details of the whole subject without any omissions, though we may find at the end that some of our notes are not pertinent to what we are looking for, so we will begin with the light, and then go on to the sound, shape, action, and so on of the aurora, and lastly, collecting the salient points, happily we may light upon what we want to know.

The light of the aurora is seldom strong enough to cast a shadow, and, unless very brilliant, is overpowered by that of the full moon. It is not polarized so long as it is uncoloured, and is therefore not a reflected light but comes from luminous material. "It is rich in ultra-violet rays, and has a spectrum of a hundred lines": it is therefore gaseous. Seven of the lines agree, or nearly agree, with the lines of burning air produced by lightning, so it is probably due to a change in the material atmosphere.

People in the Orkneys, the Lapps, Finns, Greenlanders, Indians of Hudson's Bay, several scientists, and personal experience, are all in agreement as to there being a rustling sound made by the aurora: and those scientists who have not succeeded in hearing it, have failed to do so probably through not being in a proper position, for it can only be heard when the aurora passes overhead.

The production of sound would also point to the material origin of the aurora, but ice spiculæ are generally associated with the aurora in high latitudes, and they may make the sound.

The aurora is presented in many forms. Sometimes as a faint universal haze, or a few cloudy patches, and illuminated cirrus are often mistaken for these: in fact, it seems doubtful whether the so-called faint auroral lights are not always thin cirrus. In temperate latitudes the aurora usually shows as a glow on the horizon, and it may be low and motionless, or it may be slightly pulsing so as closely to resemble the light of a distant town on fire. But in the far north it is more often seen as an arc, which is not the segment of a circle like the rainbow, but depressed in the middle, which has caused it to be described as part of an ellipse, a mistake due to perspective: what we see is one side of a ring such as could be cut from a cylinder, which is suspended at but a small height and seen side on, the remainder of the ring being below the horizon. The ring does not surround the magnetic pole but appears in places towards the interior of the auroral zone.

The arch may be an even band of light, or it may send up streamers like a fiery crown: and the streamers seldom continue long in one place, but dart up and down, now here now there.

When the aurora shows this arch, the space enclosed between it and the horizon is abnormally black. It was called the gulf, or chasm, by the Greeks and Romans, and what it is nobody seems to know, but it is not confined to the aurora, as it is an optical phenomenon apparently due to light, and it may be seen on the horizon under the sun or a high full moon, showing as a dusky segment of a disc, and if the sea gives the horizon, the segment caps the band of reflected sunlight or moonlight. It has nothing to do with aurora or electricity. In Lieutenant Shackleton's

"Heart of the Antarctic," Vol. I., page 204, is a photographic illustration in which the dark space is plain to see.

Often in these colder regions the aurora passes overhead in huge wavy ribbons, draped auroras as they are called, which have bright and somewhat defined lower edges which seem to send up streams of light whose fading ends form the upper border without definition. Sometimes the streamers radiate in a tent-like form from a dark central patch near the zenith, but this is an effect of perspective, and they are in reality quite parallel to each other. When this is seen the observer is probably under the middle of a coronal aurora that would appear as an arc to observers outside it.

North of 60° in Western Europe, and of 45° in Eastern America, auroras are, in their season, of almost nightly occurrence: and they are not seen in the equatorial zone between Southern Europe and the equivalent latitude in the southern hemisphere. There is a zone on which, in the north, they appear in maximum frequency: its centre, or pole, is north of Greenland, and its periphery roughly follows the arctic coastlines of Siberia and North America, and dipping south of Greenland and low over the Atlantic it touches the North Cape in Norway. South of this line the general direction in which auroras are seen is towards the auroral pole: but inside the line the direction varies greatly.

The aurora is often associated with halos, cirrus cloud bands, and with mist, and on several occasions a curious hazy patch has been noticed where the aurora has disappeared. Now these and the dipping of the maximum line over the Atlantic, and its avoidance of continental land, would lead one to suppose that water vapour, or frozen water vapour had something to do with the aurora.

From the *Discovery*, most of the auroras were seen to the east, from which point the prevailing winds blew.

The light of the aurora is generally white, except when it is draped, when it is usually coloured prismatically, with the tints arranged red uppermost as in the rainbow, though much fainter; and often there is no colour band except the red. This would indicate that the action of the ice spiculæ with the aurora is merely prismatic, and that it is through their feeble refraction that the colour is produced, for "the colours of the aurora are paler in pure air and stronger when it becomes foggy, and draperies are only seen over open seas." This last may be true of polar manifestations, but draped auroras are seen inland in Canada.

The length of the streamers continually varies, shooting up to twice the height at one time that they do at another. Not shooting up as a flame does, but as a moving illuminated vapour would do. The rays usually dart upwards, but may go downwards, and they may, without change of length, both rise and fall, and these go by the name of the "merry dancers" in the Orkneys. In the stationary lights the light waxes and wanes gently, and never faster than twice in a second, looking exactly like a distant fire: and in the arcs it passes in pulses here and there, or to and fro along the arc.

The great auroral displays seen in Europe and elsewhere in temperate regions, and which on occasions seem to have had simultaneous action in the southern hemisphere, are visible at the same time over immense areas of land, but curiously no records are forthcoming of any of these medium latitude displays as having been seen at sea: and this is the more curious, as with the constant watch kept on shipboard, they could not have been unnoticed, and we should expect to have heard more about them from sailors than from land observers.

The auroras of the north are essentially local: and if it does so happen that one can be traced as seen successively

at several places along an east and west line, it is found that the time at which it appears is the same local time at each place, though several hours of actual difference of time has occurred: the aurora has passed along attached as it were to that part of the heavens in which it is seen, and yet it is not seen rising or setting: it comes, lasts for a time, and fades away. These smaller auroras are those seen at sea.

The night everywhere, and spring and autumn in the temperate zones are times of maximum appearances, but in high latitudes the season of the maximum is mid-winter: as spring comes on the auroras are higher, and there are none in summer anywhere.

The supposition that the height of the aurora is between fifty and two million miles above the earth, is a scholastic deduction which has nothing to do with fact, for they have been seen and their light tested and its yellow line found often enough when they have been plainly below the clouds and occasionally when not more than fifty feet above the ground: indeed, Lemstroem once found himself in the midst of an aurora, with the yellow line showing in his spectroscope from all directions round him. In the *Discovery* record we find, "a band of stratus cloud in south, altitude 10°, with aurora streamers behind it," and "auroras are torn by storms," and both storms and stratus clouds are very lowly things. Every observation in which comparison with material objects has been possible, confirms personal experience to show that the aurora is lower in the atmosphere than cloud. Anyone who is accustomed to study nature out of doors—artist, naturalist, sportsman, sailor—and who has happened to have been in the Gulf of St. Lawrence in the late autumn, will probably have seen the draped aurora, and if he has given the matter a thought would say, that the lower margin of the rays was not more than twice the height of

the ship's mast above him. Their advance from the distance has the aspect of movement along a low level, and the very excellent pictures in the *Discovery* report give this same idea of want of height very distinctly.

Why then should such enormous distances be given as the heights of the auroras seen in England and on the Continent ?

At sunset we are sometimes charmed with a fine glow of colour, and occasionally rosy rays rise above the point on the horizon behind which the sun has set: and faintly similar to these is the appearance of the auroras that are seen in these latitudes. But in what way is it possible to measure the heights of these displays ?

And, besides, there is no certainty that two persons, even when standing near one another, see the same aurora any more than they see the same rainbow. The rays, when they are coloured, are produced by refraction, and then certainly every man sees them according to his standing place. On one occasion two parties were stationed three miles apart to take the angular height of the aurora: one party signalled to the other to take the green ray: but the other party saw no green ray. But even the uncoloured light is perhaps seen in different positions by different observers: and in the case of the uncoloured aurora appearing on an east and west line at the same local time at every place, this must have been so, and no angular measurement taken at any two of these places as it passed would have been of any use in determining its height. Also lately, some photographs have been taken on a north and south line, at identical times, of passing auroras, and they differ in a way that does not seem to be accounted for by mere perspective. Altogether it would seem that every man sees his own aurora, and that the only way of finding the height is by comparison with material objects.

The grand auroras in mean latitudes are accompanied by great electrical and magnetical disturbances on the earth. " Telluric currents—which are produced by electrolytic action in the earth and which, when strong, disturb magnetic and electrical arrangements, stopping telegraph work by currents through the wires, and setting compasses vibrating—have been found to occur with great auroras." This quotation seems to include more personal opinion than description of fact. Chemical action produces electrolysis, and it is difficult to understand how a sudden outburst of chemical activity, lasting but an hour or two, can be confined to a particular latitudinal zone of a Continent without any of the action happening north or south of the zone. However this may be, the disturbance is not simultaneous with, but precedent to the aurora, which seems to be produced by the disturbance, not the disturbance by the aurora. If this compels us to ascribe these auroras to electricity in the earth, it still leaves us free to choose how the auroras result from the electricity.

The magnetic storms on the earth have recently been ascribed to electrons discharged from the sun, which, for some unexplained reason, do not continue their course to the earth, but turn off through the upper air in currents towards the poles, setting up as they travel, currents of opposite electricity in the " same direction " in the earth's crust. Such disturbances would increase the atmospheric potential gradient, between the upper air and the earth, enormously, but nothing of the sort has ever been observed, though carefully looked for during these magnetic storms: and if such an overhead current of electricity were set up, the current produced in the earth would run in the *opposite* direction to it, not with it.

No observer in polar regions has been able to find any connection between magnetism and the aurora, although

the magnetic perturbations in those regions are extraordinarily frequent and intense. What is called a magnetic storm in mean latitudes deviates the needle three degrees at the very most: while in "American arctic regions eight or ten degrees are not uncommon, and 20° 40′ has been observed"—with no aurora.

Neither has there been any manifestation of electricity on the earth ever observed during arctic or antarctic auroral displays.

The light of the aurora may be produced in any one of three ways by the various action of cohesion, but one or other of these it *must* be, whatever the primary originating cause may have been.

By gaseous molecules combining as in lightning or the will-o'-the-wisp.

By gaseous and solid molecules combining as in phosphorescence.

By change in solid molecules as in fluorescence.

These are our notes, and we have to discover from them, if we can, what produces the aurora. What force acts, and what it acts on.

THE AURORA

CHAPTER XXXV

DEDUCTIONS

Let us now condense our notes and see what we have.

The light is self-luminous, therefore produced by material. It is rich in ultra-violet rays, with a spectrum of a hundred lines, and is therefore a gaseous production. And as there are no other gases present, it must come from a combination or change in the gases of air, and perhaps of water vapour. Three of the lines are identical with those of burning air, and four almost: and concerning this last, pressure change in the material through which the spectrum is seen, may cause divergence of the lines, and very small traces of impurity in a gas may cause considerable changes in its spectrum, whether the impurity is chemically active or not.

The greenish-yellow line, which is the strongest and most distinctive, is found to be due to krypton, and is not found elsewhere except in the spectrum of the zodiacal light. As krypton is more than five times as heavy as oxygen it is not likely to form a stratum above our atmosphere, and that is only a hundred and twenty miles thick, so this forms a very decided objection to the assumed enormous height of the aurora.

The air of the stones of the zodiacal nebula must be frozen on their surfaces, and the change in the sun's rays from actinic, with no light or colour, to rays of yellow light, must be due to absorption of the rays by the frozen air and its fluorescence in recovery from whatever change the actinic rays may have produced in it. So, also, the

yellow auroral light may be due to the fluorescence of frozen krypton.

Auroras are not seen in the tropics, nor in summer anywhere: they are higher in spring: and if seen on consecutive nights, appear at the same time each night. Therefore we may judge that a certain amount of cold is needed to produce them. And cold produces contraction, that is some change in the arrangement of the molecules, and such changes produce the light of fluorescence.

We might conclude then that the aurora is produced by the condensation of the gases of air in combination, and that the curious hazy patches seen after the aurora has passed away are, perhaps, clouds of vapour of condensed gas: and that it is this condensation that produces the yellow line.

The aurora has no constructural connection with water vapour that can be traced, and yet water vapour seems to favour the aurora. Therefore it may be that the condensation and freezing of the water vapour may assist an action in the air favourable to the production of the aurora, and this is all that we can say on this point.

What force is it then that causes this action? Is it merely cohesion taking advantage of the loss of heat; or is electricity also acting; or magnetism; or is it wind?

In all regions cold is obviously a necessity, and is found near the ground in the polar regions and higher in the temperate. Electricity and magnetism are not connected with the polar auroras. They appear more often in the direction of prevailing winds. The aurora is torn by storms: it is material, and its material is moved by the wind: the auroral light waxes and wanes as though some pulsating force influenced it: no winds are steady and unchanging, always they pulsate from moment to moment and the lighter the wind the slower the pulsation: the draped auroras sweep along as though they were carried

by light winds, and they are local as though carried by local wind currents: and the coronal auroras may be in the position of descending Sowerby wind currents.

So we will assume that the wind causes a disturbance that assists some action of the molecules of the gases that have been brought by loss of heat into a condition ready for combination. Either a combination and consequent contraction producing light due to chemical change, or a recovery from some strain imposed by the cold and producing fluorescent light due to molecular change. Further than this we cannot go now.

So far we have been specially considering polar auroras in which electricity has no hand: now let us pass to auroras in temperate regions which are said to be due to electricity.

In the opinion of some, the electrical induction acting on the rarefied air in a Geissler's tube exactly reproduces the appearances seen in the great auroras, and they quote this as a proof that all auroras are produced by electricity, or are "a form of electricity" (a very loose expression) and nothing else. But we can see plenty of lights produced without electricity, and unless the yellow line has been seen in the Geissler's tube, which is not so far as we know the case, the discussion of the action in the tubes hardly seems to apply.

There is certainly no rarefaction of air acting in polar auroras, and there cannot be much in temperate zone auroras: there is electrical disturbance along with the latter, but entirely wanting in the former: so we will not change our assumption as regards polar auroras on account of appearances in the tubes.

But our deduction must be different as regards the grand auroras from that regarding the polar, because the premises are different. These stretch over vast areas, and their light is steady, or slowly changing: not such as would be occasioned by a gusty wind, but just what a

continuous current of electrical induction should cause. They are seen over land where electrical induction is possible, and not over sea where there can be none: and they follow electrical storms in calm weather. The only conclusion that appears consequent on our data, is that the induction vibrations induce, in the cold upper air, that change that the wind assists in the polar auroras.

It is a pity that we cannot make a certain deduction in either of these cases, but the above is all that the available evidence points to. When we know more—and there is certainly more to be discovered—a more decided judgment may be given. Hitherto, there has been a great lack of system in the investigations that have been made, with too much hard and fast adhesion to some particular theory, and in the majority of records a careless disregard which has confined the observations to "a fine show to-night," or some such small talk. Let some of the fine fellows who go to the dangerous polar regions set down every detail that they can observe about these beautiful phenomena, and then we may be able to decide without theorizing—that is guessing.

As to the colours of the light, their prismatic sequence proves their optical causation. The white light has been found to be unpolarized light produced by the aurora itself: but the coloured light is this white light, or part of it, refracted by ice crystals.

* * * * *

Before we leave this lecture let us consider a little more fully the idea of the emission of particles from the sun.

This is said to be possible owing to the minute division of material, and electrons and corpuscles are names that are given to these ultimate particles that are supposed to be emitted. It is held, that the more divided material becomes, the less action the natural forces have upon the

particles, and that they have none at all on these infinitesimal forms. That, in fact, the forces act less on the two halves than on the whole piece.

However small the ultimate particles may be, our earth is made of them and should therefore weigh nothing if the above is true.

The idea of loss of action of gravitation on the more minute particles seems to have arisen from an apparent difference of its action on bodies in a medium: but this is through misconception of two actions—that of gravitation which acts on the mass, and resistance in a medium which acts on the surface of the mass.

A solid iron ball will sink fast in water, while a hollow iron ball of the same outward size weighing but slightly more than the water it displaces will sink slowly: the action of gravitation on every atom of iron in either ball is the same; and the pressure of the water on the two surfaces is the same; it is the difference of surface in proportion to mass that makes the difference in the results. The dust of Krakatoa took three years to settle, while the larger pieces of the mountain fell, at once, into the sea close by: the action of gravitation on every atom, in either case, was the same, but the dust particles were composed of so few atoms and had so much more surface in proportion to mass to oppose to the pressure of the air, that gravitation took a longer time to overcome the resistance of the air. In absolute vacuo, where there would be no opposing medium, the two balls, and the dust, and the rocks, would all fall together: a molecule would fall as fast as a mountain because the action of gravity on every molecule in either case would be identical and there would be no opposition to its action.

Our material cannot leave the earth, because at our distance from the sun, our gravitation is stronger than the sun's: nor can the sun lose any material for a similar

reason. A lighter material will rise above a heavier because pressure being equal on equal surfaces there is less gravitation of mass to be overcome in one case than in the other: and nothing can escape into space because there is no attraction in space of itself. To far beyond the moon the force of gravitation towards the earth is greater than any force of any member of our solar system away from the earth, and therefore we hold our own: but if it was not for our motion round the sun we should be drawn into it—is it possible then that the sun with such tremendous power of attraction could send one corpuscle towards us.

Another name that has been found for the ultimate particle is prolith, which is considered to be the origin of mineral substance.

Protoplasm we have, and we can see it, and handle it, and consider it, if we can, as the origin of animal matter: so why not undiscovered prolith as the origin of the mineral. Prolith is called THE discovery of the age, and is supposed to explain to us the origination of the universe. But neither real protoplasm, nor mythical prolith, take us any further in the search for origination than that old blank wall beyond which there must be nothing or eternity.

No part of the infinitesimal idea is probable, provable, or needful for real research, so why worry with useless fancies while there is plenty of real work to be done? Give them a little time and all these fanciful ideas will be put on the shelf along with phlogiston, latent heat, and other follies of the past.

ST. ELMO'S FIRE

CHAPTER XXXVI

NATURAL GLOW DISCHARGE

An electric glow discharge is sometimes produced by nature unaided by science. St. Elmo's fire is an instance, and the following description of it is an extract from the "Memoirs of Admiral Forbin of the French Navy." "The night suddenly became profoundly dark with terrible thunder and lightning. We saw about the vessel more than thirty St. Elmo's fires. Among them was one at the top of the vane of the mainmast, more than a foot and a half high. I sent a sailor to fetch it down. He called out when he was at the top that it was hissing like wet powder in burning. I told him to take off the vane and bring it down, but when he lifted off the vane the fire moved to the top of the mast and could not possibly be removed. After remaining for some time it gradually disappeared."

The most notable instance of St. Elmo's fire seen by the author was in 1851. Near Cape Clear, the foremast of the steamship was struck by lightning and carried overboard, in a storm, leaving a jagged stump about five feet high. This appeared to be blazing with blue flames which the pouring rain could not put out, nor the stormy wind drive away, and which did not burn the wood, but which rose and fell with the fall and rise of the bows of the vessel. How long it lasted he did not see as another subject diverted his attention: one of the sailors had his hand smashed and went to the doctor to have it seen to. Two other poor fellows had lost their lives with the fall of the mast.

Dampier writes, "July, 1687, near Macao. An awful gale from N.E., and dreadful thunder and lightning; about four the storm abated and we saw a corpus-sant at our main-topmast head, on the very top of the truck of the spindle. This sight rejoiced our men exceedingly, for the height of the storm is commonly over when the corpus-sant is seen aloft, but when they are seen lying on the deck, and creeping about the scuppers, it is generally accounted a bad sign." It was a mistake on Dampier's part to call those lights creeping about the deck corpus-sants, for these only appear at the ultimate points nearest the influencing clouds, and those creeping lights must have been electric fire-balls.

The presence of St. Elmo's fire on the mastheads is not, however, always a sign of danger past. "1794, January 9th, the East India ship *Dover*, in latitude 47° north, and longitude 22° west; a gale of wind with lightning and thunder. Sundry very large corpus-sants appeared overhead, and settled on the spindles and seemed like large torches. A flash of lightning struck the ship, dismasted her, and stoved the deck, reversed the compasses from north to south, and they wavered about and became of no use."

The appearance of corpus-sants is not confined to shipboard. Cæsar saw it in the African War during "a frightful storm with hail of uncommon size; the points of the javelins of the fifth legion appeared all in a flame, and shone with a spontaneous light."

Transactions of the Royal Society, 1774. "1st March, 6 p.m., Mr. Nicholson, returning to Wakefield, saw a storm approaching from N.W. 'I made haste homeward, but observed a flame of light dancing on the ears of my horse, and several others much brighter on the brass ferrule of my stick. Five or six graziers overtook me. They all had the same appearance, and one in particular,

who, when he arrived at an inn, called for a candle to examine his horse's head, as it had been all on fire, and he thought it must certainly be singed. In twenty minutes it abated, and the clouds divided . . . a light was said to have appeared on Wakefield steeple.' "

The same sort of thing occurs sometimes to the mountain-climber. Mr. Church in "Science" gives a description of a display on Mount Rose in California. There is an observatory on the hilltop, and in it a party of visitors took shelter from a storm of snow and hail. When they left the building, "every artificial projection on the summit was giving forth a brush discharge of electricity. The corners of the eaves of the observatory, the arrow of the wind vane, the clips of the anemometer, each sent forth his jet, while the high intake pipe of the precipitation tank on the apex of the summit was outlined with dull electric fire. Whenever our hands arose in the air, every finger sent forth a vigorous flame, while an apple, partially eaten, in the hand of Captain Brambila, sent forth two jets where the bite left crescent points. This latter phenomenon occurred, however, only when the apple was raised above the head, and ceased when it was lowered, so that the eating of the apple involved no visible eating of flame."

Darwin, speaking of the effect of induced electricity when in the Andes, says: "My flannel waistcoat when rubbed in the dark appeared as if it had been washed in phosphorus." Sometimes the feeling produced by the escape of the electricity through the skin is disagreeable and even painful: Saussure felt as if wasps were creeping up his back and stinging him: and other travellers have complained of more or less painful irritation.

St. Elmo's fire sometimes appears as a flame the size of a man's head, but more often it is much smaller as a flame, and most commonly it is merely a glow with

scarcely any extension into the air. Captain Fitzroy says of it, in his book on the surveying cruise of the *Adventure* and *Beagle*, that it resembles the light made by "a piece of phosphorus or a glowworm, and not quite so large as the flame of a candle."

It is usually stated, in explanation of this phenomenon, that a lightning flash is imminent, and that the electrical stress is only prevented from violent rupture by the quiet discharge thus given by the conductor. Certainly, so far as experience goes, lightning seldom follows this display: it may go before it, but when St. Elmo shows his light the danger may be said to be over. Sailors have looked upon it as a safeguard for ages: Jason on the *Argo* took it as a sure sign of a prosperous voyage.

What it means is, that the air for some reason is more than usually averse to electrolytic action, and refuses to carry on the effect: the induced electricity on the earth is trying to escape, but has to be content with getting away in this slow manner, by changing its force to the work of driving of the condensed air gases from the point, and causing a chemical combination of some of the oxygen and nitrogen. St. Elmo's fire is a brush discharge, and it has been found in all brush discharges that have been examined, that there are products of the combination of oxygen and nitrogen in the discharge, and that it is these chemical combinations that, for the most part, give the light of the discharge.

The advance of a denser cloud may increase the force of the glow, but there will be no flash unless the cloud nearly touches or at any rate comes close: and the cloud is emptying itself in the same manner from all its points. The air will not act as conductor and neither the earth nor the cloud can make it act, because most of the chemically active dust and the moisture particles, which alone can convect electricity in the air and which would have

helped the action of the air, have gone to the clouds. "Before and after the passage of a storm-cloud the air is remarkably free from electricity," and if the air could be examined during the passage of a storm, it would be found to be just as free as it was before and after, but its state at that time cannot be ascertained instrumentally, as the instrument is charged by induction of the earth and clouds. An increase in the distance between the clouds and the earth would naturally act in the same way to prevent conduction.

This fire, from all accounts, is specially associated with strong winds and hail. Now, so far as personal observation goes, hail comes from high clouds, and wind drives clouds away and raises them, and in both cases there is distance between the influencing bodies which must increase their difficulty of discharge by electrolytic conduction. But the charge in the cloud being considerable, its influence is great, and causes a corresponding exertion of influence on the earth beneath it, and in consequence these brush discharges, which are called St. Elmo's fire, are given off, from available points.

* * * * *

The apparition called ignis fatuus, will-o'-the-wisp, and other names, though it very much resembles St. Elmo's fire as it is usually seen, has nothing to do with electricity, but it is a strange sight, so the following description, taken from notes of one seen by the author in the Lushai Hills in India, is worth recording.

The day after we stormed Koongnoong we occupied the village, which was of nice clean and large houses built on raised bamboo platforms, and that night I took the rounds to relieve the man on duty. The sentry at one end of the village had his post near by the cliff at the edge of a pit about forty feet deep, with walls of

perpendicular rocks enclosing it in more than a semicircle: there were shrubs and long grass growing on the ground below which sloped gently to the open hillside, and the place was no doubt a depositing place for cast-off rubbish from the village. For a moment I thought that there were people with lights below, and I said to the sentry, who are those? God knows, Sir, they are not men, said he, and then I knew that they were Jack-o'-lanterns. It was as though invisible ghosts waved ghosts of torches. The lights had the shape of flames, broad not high, of a pale blue and giving little light. They moved with every breath of air, floating away and returning to their places again, some on the grass and others on the tops of the bushes; or seeming to be blown out and to start somewhere else. It is the bad air of that dirty place burning itself away, said I to the sentry, and it seemed to cheer him up a bit, but he was a Ghoorkha and I dare say had seen such things before in his own hills. There were twenty or more of the lights flickering about. This was written by the light of a splendid full moon by which the smallest print might have been read. We were at a height of over 5,500 feet.

FIREBALLS

CHAPTER XXXVII

NATURAL GLOW DISCHARGE

THE name fireball is given to several objects, including meteors, an artillery shell, and an incendiary missile, none of which have any connection with electricity, but the phenomenon so named which we are now considering is electric, and probably is produced in somewhat the same manner as St. Elmo's fire. It is, however, of much rarer occurrence: few persons have seen St. Elmo's fire, and fewer have even heard of electric fireballs: and the author thinks himself peculiarly favoured in that he has seen two. To arrive at a decided opinion as to what they are is not to be done even with the help of other descriptions, for they have been so seldom seen, and then have passed so quickly, that there has been no examination possible of them, and as for conjectured theories based on mere descriptions, any one person who knows anything about electricity can make them pretty nearly as well as any other. So far then as instruction in electricity goes, one might pass them over, but they are such splendid objects that it would be a pity not to record what one knows about them, so we will therefore give them a chapter.

About the year 1844, a fireball was seen at Montreal, Canada. The situation was as follows. The author was in the open verandah, facing south, of a country house, in front of which was a lawn about twenty-five yards across, with large trees beyond. The fireball came from the north-west and passed obliquely towards the south-east: it bounded lightly across the lawn touching the grass in two places, and striking the ground at the foot of one

of the trees, sank in, tearing open the turf and throwing up a little earth as it did so: there was a slight dull sound from the ground where the ball disappeared, but none before that, either during its flight or on striking, and the grass was not damaged where the ball touched the lawn. The distance was not more than thirty yards from where the ball came in sight to where it sank. The ball was glowing white, the size of a large round football, its glow prevented it from having any determinate outline. It seemed light as a bubble and went no faster than a man would go when taking a quiet walk. It was unfortunate that the origin of this fireball could not be seen, but a greenhouse closed the end of the verandah in the direction from which it came. There was no rain, and it was a clear and quiet summer afternoon.

The author saw another fireball in 1877 at Shillong in the Khassia Hills in India. Its appearance was like that above described except that it was decidedly yellowish in colour. It appeared near the top of a small pine-tree at about twelve feet above the ground: it came down the side of the tree quite slowly taking full three seconds to do so: it then entered the ground at the foot of the tree and opened a furrow about fourteen feet long in a straight line away from the tree. Its origin was apparently where it was first seen on the tree, there was no previous sign of it. The furrow in the ground was of an even depth and breadth of about fifteen inches nearly to its end. No sound was heard, but there was a strong wind blowing which would no doubt have deadened slight sounds. The soil at that place was peaty leaf mould about eighteen inches deep, overlying a very hard red clay: the earth was very wet, but not the clay except where its surface touched the earth. The wind, which was blowing very strongly, did not disturb the fireball in the least, but it came down the lea-side of the tree. There was no rain.

These two fireballs were surrounded with a dazzling glow such as we see round masses of white-hot metal, and very much recalled such glowing masses except in the sense of weight and heat that the metal conveys. These seemed cold and as light as air, as if they could be blown away like feathers, which was certainly not the case with the second. Both of them appeared in the daylight between four and five in the afternoon.

The following are some extracts from books:

"M. Colon, Vice-President of the Parisian Geological Society, saw one of these singular meteors leisurely gliding downwards along the bark of a poplar. It took at least five or six minutes to reach the base of the tree, as if unable to overcome the resistance of the air: but on touching the ground it rebounded with a wonderful rapidity, and disappeared without exploding."

Royal Meteorological Society's Journal. Referring to the line squall of February 8th, 1906. "Two well authenticated cases of globe lightning occurred during the storm. One occurred at Haverhill in Suffolk. Mr. R. Ruffer supplied the following description. A ball of fire as large as a cocoanut, leaving a trail behind it, struck the mill about forty feet up, and ran down the bell-wire and chain, melting the former and sending it on the white-washed wall like electroplating. It set the links of the chain together, so that great force was required to separate them. I saw the fireball about the size of a large orange on the chain about forty feet up the mill, about one and a half yards from me. It stood still for a short time, and then went down to the bottom floor and exploded like a cannon when it came in contact with the ground. This happened at 2.30 p.m. on February 8th. I was surprised to find after the explosion that very little damage had been done."

"December 7th, 1848. *H.M.S. Rodney*, seventy-four

guns, was struck with lightning in the Mediterranean: the iron hoops of the masts were all broken and magnetized. Fireballs, or corpus-sants, rolled about the deck, and the men ran after them to throw them overboard. Four men were killed." These men, however, were killed by the lightning and not by the fireballs.

A picnic party took refuge in a barn from a storm. This was in June, 1826, in the Malvern Hills. "The electric discharge appeared as a mass of fire rolling along the hill towards the building in which the party had taken shelter, and two young ladies were struck dead." This may have been a fireball, or it may have been a streak of lightning seen end on.

Fireballs often have the name but should not be confounded with globe lightning, or ball lightning as it is variously called, that is, lightning discharged as a ball from a cloud, and which is a thing that probably never occurs, though every year we read descriptions of it. Here is an instance. A professor was standing at a door watching the approach of a storm: he saw a ball of fire start from a cloud and strike the ground about fifteen feet in front of him. Speaking of it afterwards to some of his friends he described it as ball lightning. Some of them who had seen the flash assured him that it had been an ordinary streak of lightning. He had seen it end on.

In the extract from the *Meteorological Society's Journal,* already given, it said that two cases of globe lightning occurred in the storm of February the 8th, 1906. The second was as described below by the Rev. Allan Coates of Barsham Rectory near Beccles. "Between 2.15 and 2.30 p.m. I was sitting in my study, which faces west, with my back to the window. I heard some rumbles of thunder, and then a very brilliant flash of lightning caused me to turn round and look out of the window. Between this flash and the thunder I counted twelve or

thirteen. In about a minute it began to rain hard, and I saw a very vivid flash of zigzag lightning from west-north-west passing to north, and in the limited field of vision between a tall cedar and a large clump of yew-trees it seemed to be almost horizontal, slightly inclining downwards towards the north. The wind was then blowing from the north-west, and it began to hail. I counted five or six before the thunder came. Then almost immediately, in the north-west, there appeared a huge circle of light, giving the impression of the heavens being opened, most vivid, and in size, as far as one could judge, two or three times the diameter of a setting sun. It appeared just above the cedar in height, but not near it in distance from me. *At the same moment* an appalling crash came like the bursting of a big shell immediately overhead. This was, I suppose, the moment at which the east end of our church, a hundred yards from this house, was wrecked. The circle of light was visible for some appreciable time. The hail turned to snow and there was no more lightning."

His wife and daughter saw the flash like a great sun which "seemed to travel over the house. If so, it would also pass over the church, and coming from the north-west would naturally disappear in the south-east as the gardener says."

"My gardener, looking out of the stable-door facing south-east, uses the same expression as I have just done, viz., that the heavens seemed opened above him, and two huge arms of yellow light seemed to come together and joining strike the earth to the south-east. This might have been what set on fire the farm at Brampton some four miles south-east of this."

This was evidently a flash seen end on. The first flash seen was nearly horizontal and so also was this one. It divided into three branches after passing over the house, one striking the church, and the other two converging

and perhaps striking the farm. The really curious thing about these flashes is their avoidance of the ground directly under the storm-cloud, and their running long horizontal courses. It was raining hard so that it was not from want of moisture of the earth underneath that the currents did not go to it. The only conceivable reason is that they followed the track of dust particles closing in to join the cloud, such track offering a better conducting medium than the air cleared of dust below the cloud.

The *Times* of 17th February, 1909, reprints the following from its issue of the same date in 1809. "We have been favoured with the perusal of a letter from on board the *Warren Hastings*, recently launched at Portsmouth, and now moored at the Mother bank, which states a singular occurrence that took place on board that ship on the 14th instant, for the truth of which we can vouch":—

"The morning being fine, it was deemed necessary to get up the topgallant masts, which occupied some hours. About three o'clock in the afternoon the atmosphere was overcast to the westward, and every appearance indicated the approach of a violent storm. Several alert sailors were sent aloft to strike the topgallant masts as speedily as possible, but while lowering them the wind blew tremendously, and the rain fell in torrents, accompanied by heavy claps of thunder. In the midst of the confusion occasioned by the storm, three distinct balls of fire were emitted from the heavens; one of them fell into the maintopmast cross-trees, killed a man on the spot, and set the main-mast on fire, which continued to blaze for about five minutes, and then went out. The seamen both aloft and below were almost petrified with fear. At the first moment of returning recollection, a few of the hands ran up the shrouds to bring down their dead companion, when the second ball struck one of them, and he fell, as if shot by a cannon, upon the guardiron in the top, from

which he bounded off into the cross-jack braces. Finding that he still survived, he was relieved from his perilous situation, and brought upon the deck with his arms much shattered and burnt. This poor fellow was expected to undergo immediate amputation, as the only means of saving his life. The third ball came in contact with a Chinese, killed him, and wounded the main-mast in several places; the force of the air, from the velocity of the ball, knocked down Mr. Lucas the chief mate, who fell below, but was not much hurt. For some time after the storm subsided, a nauseous, sulphureous smell continued on board the ship."

This is plainly a case of ordinary lightning seen end on: three flashes following each other on the same track to the same mast. It is curious how these old-time people likened all strange smells to sulphur fumes. King James in his counterblast says that tobacco and that pit that is bottomless have a similar sulphureous, horrible, stygian smell: and here we have the same savour attributed to ozone.

Many more instances could be given of so-called ball lightning, but they would not illustrate the question more clearly than those given: and anyone who desires further information should read M. Flammarion's very interesting book in which all sorts of lightning and effects occasioned by and attributed to lightning are given, and he can exert his ingenuity of mind in discriminating how much in the stories is due to electricity, how much to other circumstances, and how much to lively imagination.

Mr. Alfred Hands believes that both fireballs and ball lightning are due to imagination or delusion, and has written to say so in the *English Mechanic* of the 13th August, 1909, in which he gives five instances, two of which are due to reflection from metal plates and one to a small waterspout. He is, no doubt, right as to all

instances of globe lightning, but not to all instances of fireballs. Some of these may have been instances of St. Elmo's fire followed by lightning, but some have very certainly been moving globes of light detached from solid material.

It will be understood, from what has been described, that there will always be some difficulty in arriving at a precise knowledge of the constitution of fireballs, but this much we assuredly know regarding them, and that is that their light must be due to chemical combination, and we may also say with certainty that it is a combination of gases, and that the combining gases are the gases of the air. And this points to what may prove to be the explanation of the phenomenon: and, in fact, Professor Righi has performed an experiment which appears to confirm this idea. He passed a strong current of positive electricity through a tube containing highly rarefied nitrogen, and instead of the luminous glow that ordinarily appears, he produced a patch of light that moved slowly along the tube, one way or the other, according to the strength of the current used.

This patch of light was certainly due to the combination of gases in the tube at a point that marked the crest of a wave of augmentation of chemical combination due to the interference of electric influence æther vibrations. Whether such an action can occur in the open air is a question, but theoretically it would answer perfectly for the production of fireballs. There is in these two phenomena of the tube and the air, nothing that we *know* to be in common except their lights—the radiant vibrations of æther that they project—which can only be produced in one and the same way: that is by the contraction of molecules in combination: so beyond this we can only theorize as to the identity of the causes that produce these contractions.

Since writing the above the following has been published in the *Royal Meteorological Society's Journal* for October, 1912, among descriptions of thunderstorms in July and August of that year, by Spencer C. Russell. "13th July. Thunderstorm at 2.6 p.m. . . . During this storm at 2.31 p.m. there was a vivid flash of fork lightning from cloud to cloud immediately followed by the formation of a round incandescent globular ball, about the size of the full moon, bright white in colour, due south, which remained visible about fifty-five seconds, and travelled slowly at a considerable elevation, becoming lost in heavy rain and cloud."

Also in the *Bulletin of the Astronomical Society of France* for October, 1911, there is an article on the caprices of lightning, in which four instances of the occurrence of fireballs are mentioned.

LIGHTNING

CHAPTER XXXVIII

PRODUCTION

We will now try—with the help of facts that we have learned in the laboratory, and that we have seen in nature—to find out the history of lightning. And first as to its production. To make the study thorough we must begin with weather conditions.

When there is a change to rain coming on it happens in two ways, which the gardener distinguishes as weather, and thundery weather. There are lots of modifications, but only these two fundamental courses. The first is when we have rainy weather. There are cirrus clouds in a pale sky: a draught of intermediate air blows under them, and its vapour, being shaded from sunshine, condenses to cirrostratus: another layer forms under this from a cross current, and as many as five or six layers may be thus spread out, each augmented by vapour from below, and rain may be falling from three of them before the lowest is complete. This is how a rainy day originates, and it may come with much wind or little, and end in a simple downpour, or a cyclone, or a straight blow: but there is no lightning. There seems to be no electricity in these clouds, and if there is any it must be bound in each layer by the influence of that which is in the layers above and below. Of this sort are our winter storms. They are bred from Atlantic vapours and exhibit no electricity.—Why?

The other way of change is when there is thundery weather. To begin with, there have been several hot

days and the last is oppressive with a dull sky: in the afternoon, when the sun's power lessens, the restraint gives way: dusky patches gather in mid air and hurry to join together from all sides, and a great heap of cloud is formed, flat and dark below, and with a rounded brilliant white top. It is several miles in area and perhaps a mile high: and the sky above it is of a beautiful pure dark blue, because all the vapour and the dust that was in the air have gone to make the cloud. There is no wind with this cloud except just below, for wind prevents its formation, and if the wind below has any strength, it is only because of the small gap between the cloud and the earth that it has to pass through. Rosy lights of small discharges may sometimes illumine the cloud momentarily as it nears completion: then there is a dazzling flash, a terrific peal of thunder, and a deluge of rain: but the rain was formed before the flash. This is the type of our summer storms, they are bred over the land and are full of electricity. —Again, why?

When we come to think over the processes that can possibly lead to the formation of clouds and to their charging with electricity, and try to pick out a material and a process by which these things can be accomplished, we at once say that it must be by water vapour and its condensation: the cloud is most certainly formed of condensed water vapour, and the vapour, no doubt, rises from the sea already charged with electricity, and the cold in the higher regions of the air condenses the vapour to cloud and the business is done. It is so simple an explanation, so self-evident, and so little requiring of thought, that we accept it at once without question or experimental proof, just as the old scientists did, and on their authority this explanation has ever since been taught in our schools, and it is absolutely wrong.

Evaporated water has been proved by many careful

experiments to have no electricity, and the reason is that when it rises in evaporation, it is an invisible gas made up of separate molecules, and in this state it cannot be electrified. Each vapour molecule consists of two atoms of hydrogen and one of oxygen and the electric action requires the interchange of the oxygen atom with a like atom from another molecule, and this cannot be done as long as the molecules are separate: but when the vapour becomes in its second state visible through partly condensing, and we see it as cloud, it then can take on the electric action, so that there is no difficulty about the charging of the cloud after it has formed, provided the electricity is somehow conveyed to it.

It is plain that the separate molecules of water vapour can have no skins, so that in that condition they can join together; but while floating in air they are kept separate and single, by the restraint of heat, until they have gained a height where the cold of the air reduces the effect of the sun's rays so much that they can come together and condense into the minute globes of water that form the clouds. As these little globes are visible with the help of an ordinary magnifying glass, they must contain millions of molecules: and as they can remain in this state unchanged for a long time, it is evident that they have arrived at a size when their water skins are fully developed and capable of preventing any further joining together: and that therefore they cannot after this form raindrops unless they have some assistance.

Now, after eliminating evaporation, we have nothing to fall back upon to electrify the cloud except the electrified dust in the air, and which is carried with the water vapour into the cloud. No action of friction of particles, or any other means of electrical production, in the cloud, or in the air, can make any change as there is no machinery there for separating the two electricities that would be

thus produced: so it is the dust that charges the cloud with the electricity that it has brought from the earth.

Besides electrifying the cloud, the dust also helps in the formation of the raindrops, and the concentration of the electricity. Lord Rayleigh discovered that "electrification of water particles causes them to unite into larger drops." The positive electricity on the surface of the dust grains sends out influence vibrations that break up the water skins of the globules: and they fly to the dust grains, where they cohere, and thus drops too heavy for the air to support are gradually formed, and they fall together and join together till they make raindrops.

While this last combination is going on, the larger the drop becomes the less surface it has in proportion for the electricity to occupy, and, given an opportunity, the charges will dart away. There is also on this account a great accumulation of electricity in the lower part of the cloud: it is all positive and it draws the equal quantity of negative electricity that it left on the earth towards that part of the earth's surface that is under the nearest part of the cloud: and the positive being the easier to move, as soon as it is strong enough to force its passage, it seeks the earth in a flash.

Electric conduction, whether positive or negative, consists of a force and an action caused by the force. In order for the force to pass from one point to another it must be strong enough to cause a change all along the line between the two points. The change is caused by the force, but the force cannot get across without the help of the change. It is like a man running up a ladder; he does all the work, but he could not get along without the rungs. When, therefore, the electric force in a cloud has accumulated to such an amount that its influence vibrations can strain the air to chemical action along a slender track to the earth, it passes down and its track is shown by a

streak of light. We call it an electric flash, and quite wrongly, for what we see is the chemical combination of the oxygen and nitrogen of the air which burn vividly together. Electricity has neither light nor heat of itself: it is the chemical action of the materials that it uses that makes the light and heat.

Some things are known as good conductors of electricity—copper for instance—and a good-sized copper lightning rod will carry off any charge of electricity that nature can produce without giving any indication that it has done so: because condensed air is apparently the very best of conductors, and copper interferes hardly at all with its work: but if the rod is broken, though the gap may be of the narrowest, the badly conducting air in it would offer so much resistance that enough heat would be developed by its combustion to fuse the ends of the rod, the chemical action producing both heat and light.

* * * * *

Writers have declared that it is an inexplicable mystery how a flash a mile long can be produced by a cloud. The way for the flash is helped, no doubt, by the water vapour in the air, water being a very much better conductor than air, but for the greater part it is the air that conducts the force, and the resistance of air to conduction is strong. Still all the electricity of the cloud tends towards its lower part, either carried there by raindrops, or drawn by the attraction of the earth's opposite charge, and there are several cubic miles of cloud to gather from, and that surely ought to supply enough to force the passage: at any rate it is enough to produce the long sparks we see.

It has been found that the stronger the charge of electricity, the more easily it breaks down the opposition of the air. A force of ten thousand volts will make a spark in air an eighth of an inch long: but a force of twenty

thousand volts will make a spark half an inch long. That is to say, that with twice the power the spark is made four times as long. So probably the force needed for a lightning stroke is much less than is generally calculated.

The volt is a measure of electricity that represents about five-sevenths of the force of a standard cell in which is a zinc plate about half an inch long by a quarter inch broad. The volt is five-sevenths of the force produced in a second by the chemical action on this plate. Let us suppose that one volt of the force that this little plate produces can electrify some measure of dust in the cloud: nobody knows how much, but let us be liberal and say that it is the dust in ten thousand cubic feet of cloud. Then from a block of cloud twenty thousand times as big we should get a spark half an inch long: and as there are 736 such blocks in a cubic mile, each cubic mile of cloud would give us, according to the geometrical proportion of four times as long for twice the voltage, a flash more than three miles long.

*   *   *   *   *

The discharge of a cloud may happen in other ways besides through a flash of lightning. Rain would do it if the whole cloud changed to rain: each drop would carry a small charge. "Smoke discharges atmospheric electricity slowly but surely and thoroughly. The German peasants have a traditionary saying, that when a storm comes, as much smoke as possible should be made in the stove. Professor Schuster, quoting from statistics, shows that in 1,000 cases of lightning stroke, ·3 are factory chimneys, and 14·8 are churches, and mills with no fires burning." The smoke-dust evidently forms a channel for discharge, probably by convection. Smoke would thus prevent lightning stroke in a storm, but under a clear sky it helps with other dust to electrify the atmosphere.

Perhaps, also, smoke acts sometimes as a conductor by assisting the conduction of the air, for there have been cases where the smoke certainly appears to have induced the lightning to pass down the chimney into a house.

In the Himalayas the people will not burn rhododendron wood, as they say it brings thunder and lightning. This tree, stunted and crooked, is often the only one to be seen on the grass-covered tops of the hills, and former hunters and herdsmen using such places would have used the wood for their fires, and the smoke from them might have brought down a flash, which not finding earth easily in the fire, destroyed the men near it, and one or two such incidents would send the men to lower parts to camp where they would find other fuel, and there the smoke would bring them no harm, and so by deduction they would get their idea about rhododendron wood. On the side of the hill the stress of the electric charges would be much less than at the top where the different charges of the earth and cloud are drawn to approach and cancel each other. In the Andes, as Darwin tells us, almost everything that was touched gave off sparks, and the hair of his dog's back stood up and crackled. Cats, they say, cannot live in those places, it would be difficult to say why, but this, fortunately, is not our immediate concern.

One can understand that the tops of the hills should often be struck on account of the stress between the charges of the earth and cloud, but besides, there are particular localities which are constantly struck, either on account of their position, or apparently because of some mineral contained in them.

There was once a house whose situation brought it ruin. It was built on the spur of a hill because from thence it commanded a magnificent view. Surrounded by high hills on three sides, the spur was between two valleys which joined into one below it, and this pointed in the

direction from which storms usually came. This house was twice struck and twice repaired: it was struck a third time while it was occupied, on account of its remoteness, by a man with another man's wife: they were killed and the house burnt down: and then it was left to ruin. This is a case of what Pliny would have called judicial lightning.

The presence of minerals certainly appears to attract lightning, and several instances might be given of hills, which were known to hold iron ore, being often struck: they are, however, in places that are not generally known, and naming them would make few persons any the wiser, but the following are three good examples of the attraction due to iron in use.

A company of Ghoorkhas was sent to help in quelling a petty disturbance. The locality was a plateau about six thousand feet above the sea, and the men were housed in a long hut of bamboos and thatch, and their rifles were ranged along the back of the hut: they were struck with lightning and fourteen men (if memory serves) were killed.

A flash came down a chimney, assisted apparently by the smoke as conductor to the iron grate, and from thence it darted to an iron bedstead, killing the son of the woman who lay sick in it on its way: it then passed down one of the further legs of the bedstead through the floor to metal in the ground floor, and so away. The woman felt nothing.

There were three clerks working in a temporary office in India, the walls of the office were of wattle and dab (reeds, bamboo, and mud) and the roof of corrugated iron. A storm came on, and before any rain fell the place was struck with lightning. After the flash the iron sheets rattled in such a peculiar way, that the men were frightened and one of them ran out through the door and was killed as he passed under the eaves. Probably when the roof was struck a great part of the electricity passed on from

one of the corners into the ground, but enough was left to charge it heavily, and the sheets of iron shook in trying to repel each other, and as there was no rain there were no trickles of water to carry away the charge, and the walls were too dry to do so: so when the man passed out with his head within four inches of the eaves, the electricity used his body as a conductor and killed him. When the other two men ran to pick him up they felt nothing, and the rattling had ceased.

LIGHTNING

CHAPTER XXXIX

EFFECT

When a series of oscillating surges is set up between two conductors, we may conclude that they give alternate positive and negative sparks, and that with each oscillation the conveying molecules on and between the conductors are moved one step in electrolysis: that is, that there is one molecular exchange and no more with each spark: and that the interchange is always in the same direction as regards the molecules of oxygen and nitrogen relatively.

And we may also conclude that in a simple discharge, where the receiving body is in free connection with the earth, that there is no oscillation and that the spark has merely a single action on the molecules. It is not meant by this that a spark uses only one single string of molecules in its passage between the electrodes, for a spark of perceptible size probably uses thousands of strings, but that there is only one interchange of components along every one of the strings, and that there is no further electrolytic movement. That, in fact, in the case of lightning, the tension on the earth being instantly relieved by the flash, that there is no surge of negative electricity towards the cloud. If we make the discharge between the coatings of a Leyden jar difficult by interposing some resistance, we prevent oscillation. The discharge through the air between the cloud and the earth is very difficult, so there is no oscillation, and no emission of negative electricity from the earth. Certainly every flash in a multiple stroke, no matter how fast they follow the first flash from

the cloud, is of the same sort as the first flash and there is no observable alternation: and multiple flashes could scarcely occur if the electricity in the cloud were cancelled by a counter charge from the earth.

In the laboratory we have seen that the spark in every case starts from the positive terminal, except, perhaps, when a negatively charged and insulated body is discharged into an uncharged insulated body, and similarly in nature the spark always leaves the positive body. A few cases have been cited of negatively charged clouds, but there have been no authentic cases of lightning from earth to cloud, and though photographs have been published which are supposed to show such flashes, they have been (so far as those seen by the author) evidently flashes between clouds in which the emitting cloud is further away and perspective makes the horizontal flash seem to rise to the receiving cloud more nearly overhead. Therefore we will take it that the cloud from which lightning comes to earth is positively charged, and its flashes are simple and without oscillating return.

Negative clouds, however, may very naturally occur, because the smaller clouds would be charged negatively by induction from the larger ones, and their electricity would be cancelled by flashes from the large clouds, and this is what occurs in some thunderstorms when there is much lightning but none that comes to the earth. These storms generally occur at night and they move slowly in a cyclonic spiral and are accompanied by little wind.

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When a lightning flash uses the material of a man, or animal, or plant, to convey it, the molecules of the object struck are simply moved one minute step in electrolysis: but as that means the momentary disorganization of every particle in the track of the current, it means death, and

there is never recovery from such a stroke. The after condition of the body through which lightning has passed confirms this. There is a very small mark of burning on the skin at the point of entry, but after that the current has spread and used the softer tissues and the blood for its conduction, and these are so disorganized that putrefaction soon sets in. The harder parts have been avoided as being bad conductors, so that the ligaments and harder muscles have only suffered from return shock and have by this been violently contracted, and remaining so the body is at once rigid.

We constantly hear of persons who have been struck by lightning and who have recovered, but they have suffered from return shock and not from the lightning. The whole of the ground under a storm-cloud is strained with opposite electricity to that of the cloud, especially towards that point which is under the nearest part of the cloud, and any person or thing standing in the strained area shares the strain: every molecule is electrolytically strained to meet the discharge, and when the discharge takes place and the strain ceases, the sudden relief gives a severe shock which may be fatal. So persons to whom this occurs say that they have been struck with lightning though they have been away from the spot where the lightning fell.

The sudden cessation of the strain in a person who is near enough to the centre to be seriously affected, nearly always produces insensibility, with temporary loss of the use of the limbs, or of some of the senses, or some other affections which pass away after a time. The name counter-stroke has also been given to this shock which is merely the release from strain and return to natural action of the molecules.

When the wet clothes are used by the current as conductors, the sudden expansion caused by electrolysis

often throws them in fragments from the body. These cases are mostly fatal: not from the passage of the electricity through the clothes, but because of the strong counter-stroke in the body. The following, though it was a case of shock from an electric wire, will serve as an example. A stoker got on the coal in his tender (contrary to regulations in the electrification area) and so brought his head near the contact wire, and received a shock which made him unconscious for several hours, and put him out of working order for many days. The day was wet and so were his clothes: a hole was burnt in his cap, his hair and eyebrows were singed and his face slightly burnt, a large hole was burnt in his sock, and a hole in his boot. The electricity passed through his wet hair, his collar which was turned up, and his wet clothes and did him little outward damage, but it affected the whole of his body with responsive return shock, and moderately disorganized the whole. Had the current gone through him it would have produced the same amount of return shock, and one direct line of absolute destruction which would have killed him.

The surface of the skin sometimes seems to be used as the conductor, and seems to be variously acted on by the current, depilation being one of its freaks, but it is curious that in the cases recorded of skin action there are fewer fatal cases than in any other kind of stroke: but the records are very imperfect owing to want of discrimination, and probably these are not cases of lightning stroke, but of return shock where the strain has not only been strong enough to raise the hairs, but also to dislodge them.

There has lately been a case of lightning stroke in this neighbourhood when four persons took shelter beside a heap of hurdles from an exceptionally heavy burst of rain: they were all thrown down and three of them were struck with the lightning which divided into three branches and

used their very wet clothes and skins as conductors. One of them was killed: his face was scorched, his clothes torn, and his boots and gaiters burst, and one of the gaiters was thrown to some distance: two others, a woman and a girl, were more or less scorched about the legs and their clothes torn and burnt: the fourth, a man, was only thrown down and recovered quickly. The flash that did this work must have been a very small one from a cloud trailing near the ground, otherwise the return shock must have killed all four.

Being under any sort of shelter seems to be a protection from return shock, and the very slightest interposition of nonconducting material will prevent the passage of electricity provided it has a better alternative route, so that a person would be quite safe who lifted a live wire with a folded newspaper or the crook of his walking-stick if dry: and bedclothes are a protection judging from the case mentioned of the woman in bed whose son was killed.

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The thunder comes from the sudden expansion produced by the combustion of the air in the track of the flash: the rumbling is due to echoes between earth and cloud and between cloud and cloud. When next you have an opportunity of hearing the thunder from a near at hand flash, listen to it attentively. The noise comes crash, crash: that is the sound from the air where the bolt struck near us, followed closely by the sound from the air where the lightning left the cloud: then after a pause you will hear the rumble of the echoes.

The light of the flash does not come from the "electric fluid" as is the common idea, but from the combustion of the air in the track of the flash. The molecules of air combine so violently in return from the action of the enormous electromotive force that has been used in forcing the passage, that they produce intense vibrations of every sort from ultra-violet to induction, and consequently the

light, which is fortunately all that we are sensible of, is very intense and acts accordingly.

When we look at a stained-glass window we see all its divisions and its leaden tracery quite distinctly, and if we look at the clear sky at night we see the stars as distinct spots of light; but if we photograph either the stars or the window, we get blurred outlines because of the diffused action of the light on the plate. It is the reverse of this however with the effect of the lightning flash, for in this case the eye is the more defective instrument and takes the worse picture, for the flash appears to us when distant as a broad luminous stripe, and if it is near, the action is spread over so great a part of the retina, that a blaze is seen "as if the heavens were opened." The photograph owing to the instantaneous duration of the flash gives sharply margined lines, but even these are too broad, for probably no spark of lightning is of more than the thickness of a telegraph-wire, for whenever the point of entry of a flash into a human body has been examined, it has been found to have made but a small mark that would be covered by a threepenny-bit, and that mark represents the area over which the action is spread by the resistance of the skin.

The cross sectional area of the condensed air covering on the largest lightning rod, which conveys the flash to earth without the slightest sign of disturbance, is certainly very much smaller than the cross sectional area of the air space which we have given as that occupied by the flash in coming from the clouds, but the condensed air-coat contains fourteen hundred times the amount of material that an equal measure of air does: and the air offers enormously more resistance to electrolysis than the liquid air does: both of which show why the electricity prefers a conductor, even though it is a long one, to pushing its way through air or any other resisting medium.

ANIMAL ELECTRICITY

CHAPTER XL

INSTANCES AND DEDUCTIONS

There are a few instances in nature of animal electricity with what may be called a definite purpose, as in the torpedo and gymnotus, which are provided with galvanic apparatus for defence and attack. The explanation of the working of the powers of these creatures has not yet been satisfactorily given, and how it is that they manage not to shock themselves is simply a marvel.

In the gymnotus the apparatus is fourfold. There are two pairs of long bodies: one pair along the back of the tail, and the other pair along the anal fin, all just under the skin: each of the bodies is divided by long partitions and with very numerous small cross divisions so close as to almost touch, and making about two hundred and forty little cells in every inch, the little spaces between the divisions being filled with a jelly-like fluid: the exterior surface of all these bodies—that next the skin—is positive. They very much remind one of voltaic piles, but are different in their working, as in these the electrolytic movement is from side to side and not in the direction of the length as in the voltaic pile.

The eel can produce a positive current which is projected through the water to a distance of two or three feet in every direction. Water is necessary for the full communication of the shock, which in air is very feeble. The following little tales will illustrate this. Some one somewhere in South America caught a gymnotus with the intention of sending it to England, but it was killed in the water in which it was kept by a water-rat. Those who have seen

this latter interesting and disagreeable creature swimming under water, will have seen that it appears to be clothed with silver. It is the air which remains entangled in the creature's hair that gives it this shiny look, and this air-coat acted as armour of proof against the electrical shocks of the gymnotus. The second story is about a torpedo, but the electricity of both creatures travels in the same way. One day a small Hindoo went fishing: he had no rod, being clever enough to play his line with his fingers after the manner of his forefathers: almost as soon as he threw in his hook he had a fish on and after a little play drew out a small torpedo: the moment the fish landed on the sand the little boy fell on his back with a cry: the fish, which had been hooked in the back, had sent him a shock along the wetted line.

It has been stated that the eel's electricity is an outcome of "vitality." This is an explanation of the *lucus a non lucendo* order. We require vitality to eat and digest our food, but the grinding could be better done by machinery and the digesting equally well done in a chemical laboratory: and similarly the eel can certainly at its will cause or cease the action of its batteries, but this is probably all that vitality has to do with it and the apparatus could very possibly be made and worked by us if we knew what materials were needed for its construction and excitation. What the materials are and how they are worked is what we want to know.

Now if one end of a piece of raw flesh is heated, its ends give a feeble electric current: they have different potentials because a greater chemical action is going on at one end than at the other, and there is electrolytic action in the juices between the ends. It is, we suppose, some similar action that produces the electricity in the gymnotus. There is an air-bladder extending the whole length of the fish: it has been found that the air in the bladders of other

fishes that have been examined contains a large quantity of oxygen which has been occluded in some way by the bladders, sometimes to as much as eighty per cent.: by compressing the bladder the inner sides of the batteries of the gymnotus would be excited by transfused oxygen and an outward positive current established at once. This is reasoning by sorites and may or may not be true. Themistocles said: "My little son rules his mother, his mother rules me, I rule the Athenians, the Athenians rule Greece, Greece rules Europe, and Europe rules the world, therefore my little son rules the world." This according to argument should be true, but like many arguments soritic, mathematic, or metaphysic, its end is plainly wrong, and so may ours be, but we will continue to believe in it till we hear of a better. The jelly-like fluid of the cells, like all animal fluids, no doubt can act as an electrolyte, but it would add to our confidence in our theory if, on examination, it proved to be a good electrolyte.

The arrangement of the batteries in the torpedo is different from that of the gymnotus. They are two masses of hexagonal cells, one on each side of the head and touching the skin above and below: the interior of these cells is divided by numerous partitions piled over one another from bottom to top, and with liquid jelly between them. There is no air bladder in this case to supply oxygen, but there is an enormous nerve and blood supply. Those who believe in the electrical action of the nerves cite this as a proof of their theory, but in reality the office of the nerves is to incite the capillaries to increased transmission of oxygenated blood, and this, if it excites the upper surfaces of the small partitions to action on the jelly-like fluid, must create a current which would give positive electricity from the upper side of the battery and negative from the lower, which is in fact what is observed. "The

upper surface gives positive and the under surface negative electricity."

It is curious that the torpedo can electrify the water to a distance of two or three feet round it. One would suppose that a circuit would be formed in the water close to the fish, and that beyond this there would be no action. Cavendish made an imitation torpedo to experiment with and was astonished to find that the water gave him a shock. He charged his torpedo with positive electricity and the current passed to the ground through the water and the legs of the table on which his tank rested until he put in his hand, when his body gave an easier and therefore preferable route. His apparatus was in this essentially different from the living fish which makes its own electricity and therefore must send out both positive and negative currents.

There is a family of fishes named Malepterurus, found in the Nile and other African rivers, which is electrical. It grows to four feet and has a soft skin. The electric organ "covers the whole body but is thickest on the abdomen and consists of rhomboidal cells which contain a rather firm gelatinous substance. The electric nerve is a single enormously strong primitive fibre branched in the electric organ." When excited by the fish the organ produces a succession of small shocks sixty to a hundred and twenty in a minute. Du Bois Raymond found that Malepterurus was but very slightly affected by induction currents passed through the waters of its tub though they were strong enough to stun and even kill other fishes.

Further experiment should be made with this easily obtainable fish.

Humboldt has left us a lively description of the method that was employed to catch some of the gymnoti for his examination. How a lot of broken-down mules and rozinantes were collected from the farms and driven into

the marsh: and how the fish laid themselves out to shock the beasts, two of which fell in the water and were drowned: and how the fishes having presently become exhausted of their power, were some of them safely speared and brought to shore. Since then no traveller in Surinam has ever seen such a hunt, nor been able to find out that it has ever been the practice, and relying on this negative evidence detractors have said that Humboldt is relating a made-up story that was told him to impose upon him, thereby making him out to be at once a prodigious liar and a gullible fool. Those persons cannot have read the original description or else they are very wanting in discernment, otherwise they would certainly see that he is telling of what he saw, and besides this, that this mode of capture was not in use and probably had never been used before, but that it was the result of a happy thought on the part of Humboldt's host, who had been fruitlessly engaged for a week in trying to get him the fish. There are some persons who take pleasure in adverse criticism, adopting it seemingly as the mission of their lives and delighting in the chance of bespattering great reputations. Theirs "is one easy artifice, that seldom has been known to miss—to snarl at all things right or wrong."

The lights of the glowworm, firefly, and other insects, have sometimes been attributed to electricity though no sort of apparatus for electric action has been discovered. The light is a phosphorescent light, quite cold, and is probably produced by the combination of oxygen with some emission from the insect, in the same manner as the glow of phosphorus is produced by the combination of oxygen with the vapour from the surface of the phosphorus. For some reason the vapour and oxygen have a very strong chemical attraction for one another, which causes them to combine so violently that they produce only the shorter vibrations of light towards the blue end

of the spectrum, and among them are none of the long vibrations of heat.

Animal electricity has been credited with a power that controls the spirits of the dead, and induces them to rap out answers to credulous questioners: and also with power to give movement to inanimate objects, causing tables to gyrate and tambourines to fly and play on themselves: but these manifestations and the interpretation of them we will leave to their believers. After all they are no more incredible than electrons and carbonaceous emissions from the sun.

COMETS' TAILS

CHAPTER XLI

Comets.

There is one set of rays that have lately been ascribed to electricity and which we are therefore justified in examining; and these are comets' tails, but before we tackle them it will be as well to see what we know about comets as a whole and to form some clear conception concerning them.

It is certain that a comet is a cluster of stones surrounded by what appears to be an atmosphere.

Comets vary in size, but in a good specimen the cluster, which is called the nucleus, is probably larger than most of the minor planets, and the atmosphere, which is called the head, extends to an enormous distance round it. The cluster may have a sectional area equal say to something between Russia and Wales, and its globe of atmosphere may be five times the diameter of the earth, and though the dimensions of the head and its nucleus change, getting larger, as they enter within our orbit, their relative dimensions do not differ much, and, so long as the comet is visible, it is plain that its atmosphere does not approach to the form of a mere skin such as our atmosphere of a hundred and twenty miles does to our earth, but that it is always many times the diameter of the nucleus. The measurement of the head of the comet is of course easily made, but that of the nucleus appears to be more difficult and astronomers seem to be shy of committing to paper their ideas on the subject. Halley's comet, which has lately come and gone, has, through careful watching, added a good deal to our knowledge, and some of the

points discovered we will particularly discuss, but all the information regarding it that has been given to the public seems to have come from outsiders and not from astronomers.

We do not yet know all that is to be known about comets, therefore if we try to fill in the gaps it must be with ideas, and the more commonsense the ideas are, the more likely they are to be found to be facts hereafter. In the description that follows facts are supplemented with ideas.

The nucleus of the comet is a cluster of loose stones held together by mutual attraction of cohesion, and the light they show when distant from the sun is reflected sunlight only. Whatever may have caused them to come together, they were cold before they did so, and though they may now grind together they certainly do not do so with sufficient effect to produce any light or even any material amount of heat, and they are still practically of the same temperature as space. As a body the nucleus is of much too small a bulk to retain heat and there is no conceivable force to produce heat in it while it is far from the sun.

Photographs of Halley's comet taken before it reached the confines of the earth's circuit show that the atmosphere was illuminated as well as the nucleus and therefore that it cannot consist of a mere mixture of gases such as is our atmosphere, for pure, dry air does not reflect light—the æther light vibrations pass through it and there is no return although there is some slight refraction, so we may be certain that the material that forms the head is not gas so long as the comet is beyond our orbit. It is a mixture of substances in the form of dust which is kept in place by gravitation towards the nucleus, and which, being dust of solid material, can reflect sunlight though not so strongly as the more solid nucleus.

No part of the comet when away from the proximity of the sun is self-luminous: there is nothing to make it so, and everything to prevent its being so: but it is different when the comet is within our orbit, for then the nucleus gives out self-produced light, and the atmosphere a mixture of that and of reflected light. This fact of the luminosity of the nucleus enables the spectroscope to show that there are several substances now present in the gaseous form in the atmosphere, and this change, there is no doubt, has been brought about by the same agency that has inflamed the nucleus.

It was discovered while Halley's comet was lately within our limit, and no doubt will be found to be a condition of every comet when near the sun, that there was a great eruptive discharge of material from the nucleus in the direction in which the comet was moving: not, you must clearly understand, in the direction of the tail which is in a line away from the sun, but at right angles to that line and flying out before the nucleus: some of the projected material being shot straight forward, and other parts obliquely and to the sides. All this effect is produced by the impact of the comet with the stones of our zodiacal nebula.

It will not be necessary for us to study deeply the subject of our solar nebula, called the zodiacal light, which extends in the plane of the sun's equator to within about two million miles of us, and has a depth at the sun's poles of about eleven million miles. It is a great cloud of stones of various sizes, some perhaps the size of a house, but none large enough to show by reflected sunlight as a separate body. It is circulating round the sun probably faster than the earth and at that part which is nearest to us has a velocity of more than fifteen miles in a second contra clockwise in the same direction as ourselves: and a comet when it comes among these stones is as often as not moving in the contrary direction at about forty-five

miles in a second: so the stones may crash into the nucleus with a rate of about sixty miles a second.

It happened a short time ago that a very splendid meteor was observed with great accuracy from two places and was found to be flying through the air at a height of forty-seven miles, and with a velocity of twelve miles in a second: and it was changed by the encounter with the thin air at that height, though going at that comparatively slow rate, to an incandescent mass that was consumed in a few moments: how enormously greater must be the intensity of the conflagration when solid meets solid with five times the velocity. On one occasion a comet was observed to be broken in two by this bombardment of the zodiacal pellets, and Halley's comet has suffered so badly that it will probably not be able to endure more than a few more encounters.

The material of the comet's atmosphere when near the sun is the result of this action and is a mixture of dust and gases while it goes on, but when far from the sun the gases would freeze and remain mixed with the solid dust, and, owing to the small size of the nucleus, there would be little diminution of the atmosphere by any sort of sedimentation of the dust even in a century.

During the bombardment the nucleus has a bright spot which is not central because the explosions on its advanced side cause that side to expand and the head also is bulged by them in that direction, but it was observed that none of the streaks of light caused by the rebounding meteors passed beyond the limits of the comet's atmosphere. The material no doubt went further but, at the moment that it left the atmosphere and its gases, it lost gaseous material with which to combine and its combustion was stopped.

On previous occasions when other comets have passed in the space between our orbit and the sun, temporary

protrusions have been noticed pointing towards the sun, or sideways, and they have been called advanced tails, but they were no doubt caused by more stupendous explosions than usual following the encounter with some of the larger pellets of the nebula and carrying the atmosphere outwards with them.

The head of the comet has always been observed to increase in size and the nucleus to become brighter as it approaches the sun, and this used to be put down to the fervent action of the sun's rays, which is an idea that has very little foundation of likelihood. Halley's comet showed both these actions though it was but little nearer the sun at any time than Venus, and Venus has always been supposed to enjoy much the same conditions of temperature as ourselves, and certainly shows no signs of combustion: and besides, with such an enormous depth of cometary atmosphere to work on, those of the solar vibrations that were reduced to heat rays would be entirely exhausted before they reached the nucleus: so we may with all confidence attribute the expansion and the increased brightness of the comet to its encounters with the stones of the zodiacal nebula, and to the actual conflagration in the comet caused by them.

There is only one more point to be noticed regarding the head of the comet, and that is that its dusty atmosphere must not be considered as dense as a London fog. The dust is probably composed of pieces of all sizes up to moderately-sized pebbles, and they need not be very thinly scattered, for although the stars are seen through the whole depth of the head, diffraction helps to allow this, and the individual particles slip so quickly past that no interruption of the stars' rays is appreciable. We know that there is an immensely greater thickness of dust-laden space surrounding the sun, and that it passes between us and many of the stars, and yet no trace of diminished

light has been observed in them on that account. The only reason for supposing that the dust of the comets' atmosphere is thinly scattered is, that if the whole of the nucleus were broken up and dispersed it could not give more than a thin powdering: for if the globe of atmosphere is fifty times the diameter of the nucleus, which appears to be about the case, then the head has just a quarter of a million times the cubic capacity of the nucleus, and each piece of the broken-up nucleus whatever its size would be surrounded by an empty space two hundred and forty-nine thousand nine hundred and ninety-nine times as big as itself. But the comets' atmosphere, judging from its power of reflection, is certainly more crowded than this, and we may reasonably suppose that when the comet was made it was a collection of material of all sizes, and that the bigger pieces collected together to form the nucleus while the smaller remained scattered in the atmosphere.

The nucleus of a comet if it is big enough will at all times occlude a star, but it is only when the comet is within our orbit and has gases in its atmosphere, due to the violent combustion of the zodiacal stones, that there can be any change in the aspect of a star owing to the interposition of the comet's head: then the light of the star would be diminished and its position would appear altered by refraction through the gases of the head.

The path of a comet is a parabola for those that come once and never return and an ellipse for those that are periodic, but in no case does the path of the comet fall in the plane of the ecliptic. If you will imagine our orbit as a solid ring with a sheet of thin material stretched on it like the parchment of a tambourine, then you have an illustration of the plane of the ecliptic, and the sun is stuck near the middle of it with half its body protruding from either surface. Now the path that a comet would take to pass

round the sun would approach this plane at some angle and would pass through dipping below the other surface and rising again towards it and passing up through the plane again at a point on the opposite side of the sun. It is therefore only at those two points where the comet passes through the plane that a comet can come in line between the earth and the sun, and it is believed that Halley's comet did this at its last visit, and that then the sun's light came to us through the comet.

The ecliptics of all the planets coincide more or less closely to the extension of the plane of our ecliptic, and the divergence of the comets' paths from this plane very much lessens the small chance of collision between a comet and a planet, but such a collision would not only be disastrous to the planet struck, but would upset the working of the whole of the solar system, and as all the planets, by their attraction, disturb the courses of comets and make them irregular, it is not impossible that this action of the planets may bring about their own destruction. However we appear to have evaded this possibility for a few million years at the least.

There is (besides this attraction) a disturbing element in the courses of comets as has been proved by a long series of observations of Encke's comet. This comet has a period of about 1,210 days, and every return of it is two and a half hours shorter than the previous one. This, as we can easily understand from what we have already learnt, is accounted for by the battering of the stones of the zodiacal nebula, which would in time reduce the comet's ellipse to a circle. Encke's comet is a very small one and only to be seen through a powerful telescope, and, on account of its small size, and its circling *with* the stones of the nebula, gets little bombardment, but it may come to sudden destruction by meeting a monster pellet, and probably all periodic comets are at last

destroyed by, and their material scattered among, the stones of the nebula.

Iron, carbon, and some other substances, have been discovered by the spectroscope as being part of the material of the comet, and the composition of its solids is probably in no way different from that of the meteorites that fall through our air.

COMETS' TAILS

CHAPTER XLII

COMETS' TAILS

When a comet first comes into sight as it journeys towards the sun, it is seen to be like a small disc, palely lighted, with a brighter spot at its centre, and with no sign of a tail: the tail only begins to appear when the comet has come within ninety million miles of the sun, that is to say when it has entered among the stones of the zodiacal nebula: and it disappears again when it leaves the nebula.

The tails of comets vary, but in what may be called a typical comet, the tail is a continuation of the head, passing back smoothly without any contraction in the way of a neck, and gradually widening out till it terminates either square-cut, or tapered like the end of a dry water-colour brush. The tail is less bright than the head, and what appears to be the shadow of the nucleus divides it into two great rays and this separation is especially marked just behind the head.

The length of the tail mainly depends on the position of the comet in the nebula: those that pass close to the sun's equator have long tails approximating to the ninety million miles' depth of the nebula in the sun's equatorial plane: and those that pass otherwhere or further from the sun have shorter tails. Also some small comets, though well situated as regards the nebula, have small tails because there is little light passing out of them from the sun, but the photographic plate can trace the reflection of the continuation of the actinic æther vibrations much beyond the end of the visible tail and until they reach

the verge of the nebula. This is a point that we must particularly remember—that the tail does not extend beyond the nebula.

Occasionally we see photographs of comets' tails showing a wavy appearance of alternate light and dull patches. This, if true to nature, is not due to any material shot out of the comet possessing the property of blazing up at one part of its course, then losing energy, and then blazing up again further on: but is due to the irregular distribution of the stones of the nebula which are no doubt more densely aggregated in some parts than in others; a condition that is known to be common to other nebulæ. However, a good deal of the abnormal variation shown in photographs is plainly due to touching up.

Short temporary tails have been occasionally seen—as was the case with this Halley's comet—weeks before the comet came within the zone of the nebula, and this is because our nebula, like other nebulæ, probably has spiral trails projecting beyond its general outline and supplying us with our shooting stars, and one of these trails showed the passage of the comet through it by reflecting the light flowing from the comet. For light is always flowing from the comet although we can see none of it until it falls on something to reflect it: just as when the sunshine coming through a window marks its course in the air of a dusty room, but has no visible track if the air is pure and free from dust to reflect its light.

"The light from the comet's tail is reflected light." The comet's tail is the reflection from the stones of the zodiacal nebula of the sun's rays that have passed through the head of the comet and that have been changed by that atmosphere to light rays. Before they entered the comet they were actinic rays incapable of giving light, after they had passed through most of them were changed to light-giving rays. Philosophers are agreed that the rays emitted

by the sun have neither heat nor light until they encounter our atmosphere, and of course they include, in this property of producing vibration change, the atmospheres of the other planets and also the atmospheres of comets which are immensely more extended than ours.

The sun is in far too excited a condition to produce any vibrations but those of the ultra-violet, which have no light-producing power until they have been reduced to the longer and slower vibrations that cause light. Before they are thus reduced by the atmospheres, any of them falling on the stones of the nebula would be reflected unchanged, and a part of those reflected to us would be reduced by our atmosphere to heat and light rays, and we should see a faint zodiacal light. But those that have passed through the great depth of the comet's atmosphere are no longer actinic but have become light-producing, and they illumine the stones, and that luminosity is reflected to us as actual light—the comet's tail.

The form that the tail shows us depends on its position and on perspective. All comets' tails are wider than the comets they come from: a tail forty-five million miles long would be actually twice as broad at its end as the head it started from, because it would be twice as far away from the sun: but if it was projected towards us, it would appear many times broader at this end, and the outlines of its sides instead of being straight lines, as they really are, would appear curved: while if the tail happened to point away from us, it would seem to be narrowed to nearly a point at the end. In most positions the tail seems to sweep in a great curve, and this is due to celestial perspective which causes all lines, except those that point to the zenith, to appear curved. Therefore if the comet happens to be on any part of the circle that passes through the sun and the zenith its tail will be seen as straight, and if away from that line it will appear to be

curved. Halley's comet at its late visit showed these diversities of appearance: its tail was curved till it came near the direction of the sun and earth and then became straight. This appearance of curvature is a deception as comets' tails are straight.

Comets have occasionally been reported as having minor divergent tails like separate threads of light, and it is not impossible that rays may be reflected from some part of the nucleus by which these lines of light could be produced, but the illustration of these lines as straight beside a curved tail is wrong: and either the lines are drawn badly, or they are the result of reflection in the telescope lenses or in the spectacles of the observer. Also comets have been seen with nearly as many tails as the ship's cat, and this also is possible if we can suppose that some grand explosion has temporarily broken up the nucleus and that each part casts its shadow.

These, and the irregular and ragged appearances that are sometimes presented owing to the irregular distribution of the stones of the nebula, are all the chief variations to be seen in comets' tails and they can all be explained by familiar causes and require no call for faith in vague and far-fetched fancies, but there are popular representations of comets which have been published lately that none but a metaphysician could account for.

Descriptions and pictures (even photographs) all agree in exaggerating the luminosity and the size of comets and some of both these sorts of productions have been published which it is impossible to make any sense of because they are inaccurate through invention, exaggeration, want of perception, and want of artistic ability. Those who missed seeing comet *1910a* and have seen these fancy flights of pen and pencil must have felt that they had lost an amazing great sight, for a meteor such as was represented would have greatly rivalled the sun in

splendour, whereas in truth the nucleus appeared of the size of a small star both pale and hazy, and neither the head nor tail was visible at all if there was even a slight mist in the air. Also in these drawings this comet was placed at every angle to the horizon but the right one which was perpendicular nearly, and many uncouth and fantastic illustrations have been given of the heads and tails of this, and of Halley's comet. In fact hand drawings of comets are often atrociously bad and grossly exaggerate every peculiarity. Photographs greatly exaggerate the light but the other details are given for the most part correctly.

A short time ago the most commonly received idea as to the production of the comet's tail was, that it is the material of the comet shot out of it either by the comet's own force or by the driving power of the sun's rays. You will agree that it is hardly necessary to take the trouble to explain that if the comet had any driving power of its own it could not use it in one direction only, but must employ it in a general all-round explosive form, so that the driving power, if there is any, must reside in the sun's rays, which taken in conjunction with solid material or even with gases is an idea that seems rather incredible. We feel none of it here at any rate; we see none of our atmosphere streaming away to space; and neither Venus nor Mercury show any signs of tails.

In fact the material theory of comets' tails does not appear a plausible one; still we are bound to examine all theories; but before doing so there is a point that we must notice. The tail of the comet is pointed nearly directly away from the sun, and in order to keep that direction it must be projected with a rapidity equal to that of light. For instance, if a comet at forty-five million miles from the sun is moving in its course at forty-five miles in a second, and its tail is forty-five million miles long and

is projected at the rate of light, then the end of the tail of that comet will be just a little more than twenty-one thousand miles behind the straight line from the sun passing through the comet: and this discrepancy is always seen and increases the faster the comet travels and the nearer it passes to the sun: but it amounts to no more than the loss that is due to the tail being projected with the speed of light, and therefore, if it is material, whatever the material of the tail may be, it must travel at that rate, as any slower rate of projection would leave the end too far behind. Any idea therefore that depends on the projection of material from the comet must account for the material having this projectile velocity of 186,000 miles in a second.

A comet moves fast but it would have taken Halley's comet about a month to have come the distance that the sun's light passes over in eight minutes. The sun is exceedingly powerful and can drive clouds of luminous material from its surface with the amazing velocity of one hundred and twenty miles in a second and there is no faster movement of material known, and yet with all its power it cannot project them into space. Halley's comet passed no nearer to the sun than sixty million miles and to project its material into space the sun must at that great distance have exerted a force six hundred times as great as that which it has at its own surface. It is of no use arguing against this that the restraining force of gravitation is greater at the sun's surface than at the distance of the comet, because the sun's force of projection, if any of it passes into space, must lose energy with distance in exactly the same ratio as its gravitation loses it. And besides, on the sun's surface, it is nowhere apparent that the sun's rays have any projecting force at all, for the solar prominences are due to purely local eruptive action of the sun's material: so that as regards

the dispersive action of the sun's rays we have no proof either on the sun or here, and the idea seems to be a metaphysical conception with no basis of fact and invented for the occasion.

Halley's comet took nearly two months and a half to cross from the other border of the ecliptic, and during that time had a tail that averaged say twenty million miles in length: and it was about half as luminous as the head—that is, if it was material, it had about half as much material in a cubic mile of it as the head had: so that the tail must have contained in it, at the very least, two hundred and fifty times as much luminous material as the head of the comet omitting the nucleus: and this amount of material must have been renewed every two minutes throughout these two and a half months and must have measured altogether, thirteen million times the bulk of the head!

A comet does not exhibit a tail till it is within ninety million miles of the sun. Are we to suppose that beyond this exact distance the sun's rays lose their power to drive the material of the comet?

The outer layer of the sun's atmosphere is hydrogen which is the lightest substance known, and yet the sun's rays cannot drive it away. Why should the rays act so much more violently on the comet's more distant and heavier atmosphere?

Why should the material of a comet's tail at one time retain its luminosity over a distance of ninety million miles and at another time not over one million?

The earth was enveloped in the tail of the comet of 1861. There was an "auroral glare" which is what one would expect, but there was not the least trace of any material added to our atmosphere. How was it that we were enveloped in the light but not in the substance?

In every part of its course the material comes with the speed of light, so even if it has lost its luminescence at

the limiting distance, it cannot have lost its speed. Sir Oliver Lodge says that "the energy of one milligramme rushing along with the speed of light is not less than fifteen million foot tons." The comet's material entering our atmosphere with that speed and energy would certainly destroy us.

And besides all this the light from the comet's tail is reflected light and not the light of luminous material.

Is it necessary to pile up further objections to the emission theory? The folly of it has become so apparent that it has now been ostensibly abandoned and electricity has been substituted.

But electricity has no light of its own, and this every scientist knows although they so constantly talk of the heat and light of the "electric fluid." The light produced by electricity, whether it is that of the lightning flash or the glow from a tube in the laboratory, is the light from contracting material: and any vibrations that the action of electricity may give to the æther are not vibrations of light, but are very much longer and more slowly recurring and incapable of producing light.

And there is no electricity in the sun to send to the comet. Electricity requires chemical combination to produce it and to conduct it, and the sun is composed of gaseous uncombined elements, and therefore neither has nor can produce electricity.

To say that comets' tails are not produced by luminous material driven from the comet by the sun's rays but of material made luminous by electricity is the substitution of *obscurum per obscurius.* There can be no material from the comet to supply the tail whether luminous or not and there is no electricity to act upon it: and the light from the tail is reflected light and not radiation from luminous material.

There seems to be a good deal of misconception as to

what is meant by self-luminous material. The general idea appears to be that it is a material that produces light without any action on the atoms of the material—there is no such material. To produce any effect there must always be a producing action. The luminosity of luminous paint or of the diamond is not simply the pouring out of light that has been poured into them, but is due to the recovery from some crystalline change that was produced by received light, and the luminosity is consequently lost by use. The luminosity of phosphorescence and of combustion is due to the combination of the materials with oxygen, and lasts only while the combination is going on, and the materials once combined are useless for the purpose again.

The "electric fluid" has no light. The examination of the electric flash shows that it consists of millions of tiny sparks, which show the combination, or as it is commonly called, the burning together of the molecules of air: and their light in the whole of a lightning flash lasts for perhaps the twenty thousandth part of a second. There is no electricity without combination which is sometimes violent combination giving light, and sometimes easy combination giving none: the current that produces light in the violently combining air could pass down a lightning conductor without showing a trace of light, because of the easier conduction: but in no case is there any light from the electricity.

To send out a comet's tail worked by electricity, there would be required a constant emission of material from the comet to supply the substances for combination, and a constant emission of electricity from the sun to work upon the substances, both of which are impossible: and as there is no material in the space between us and the sun except the stones of the nebula, there can be no possible supply of materials for combination in that

region, and there can be no light but what the stones reflect to us.

Much has been written about electricity in the sun and all of it based on a supposed connection between sun-spots and the meteorology of the earth and especially with regard to the aurora. Coincidence is the most that can be claimed, for many sun-spots are formed without any sign of meteorological change here, and meteorological changes here occur during periods—one of which lasted for sixty years—when there were never two sets of spots on the sun and what there were were very small. Repeated attempts have been made to find electricity in the sun and a short time ago the cohere, which is a very sensitive detector of electric vibrations, was used to discover whether such vibrations are emitted by the sun, but entirely without result. There is absolutely no proof of electricity in the sun and every attempt to find any has failed. Any theory that includes electric solar emission is therefore baseless.

Ideas that are wonderful and incomprehensible, although impossible and useless, are more attractive to, and more believed in by the general mind than simple statements based on facts: witness table-turning; the gyration of solid magnetic molecules; the powers of radium. And in many cases these wonderful ideas are difficult to disprove. You dream that you have fallen through infinite space. A theosophical friend tells you that your astral body, while separated in sleep from your material body, did actually fall through space. What can you say? His affirmation is as good as your negation. Your doctor tells you that you are anæmic and that your dreadful dream was due to inferiority of arterial supply to the brain. You prefer the theosophist's fancy to the doctor's more probable fact, because the first gives you a wonderful and incomprehensible and glorious (and utterly useless) extension of your being.

"As a rule men freely believe what they wish," and now, after our study of the subject, you have your choice of believing in one or another of the prevailing theories, or of concluding that the comet's tail is a true ray—a ray of reflected sunlight—and that it has nothing to do with electricity.

APPENDIX

CHAPTER XLIII

APPENDIX

"Have you ever thought it worth while," said Socrates to Alcibiades, "to try to find out, or learn, what you believe you already understand?" And the answer was, "No certainly."

Said Socrates to Theages: "If you wish to become an expert in a science, do you not address yourself to those who profess to teach it?"

This book was undertaken as an endeavour to find out whether what we understood that we had learned about electricity is true: and the result like the end of the marriage service, has been amazement.

Before this book was thought of, the writer was engaged in the search for the cause of gravitation,* and as some scientists said that it was due to electricity he turned to examine the idea, and, although he had been taught electricity, and had attended lectures, and had seen and done many experiments, he found, much to his astonishment, that he did not know what electricity is—so he bought books on the subject—nearly all of them started with the experiment, familiar to our childhood, of rubbing a stick of sealing-wax on our coat-sleeve and attracting bits of paper with it, and this was supposed to explain what electricity is, and to the writer's still greater astonishment no scientist had got any sensible idea beyond this: they knew what electricity could do, but not what it

* The cause of gravitation has since been discovered by the writer, and electricity though it is due to gravitation has nothing to do with its production.

is, and in explaining its effects they did not agree and apparently it was a case of every man his own electricity, so the search for clear and indisputable teaching was disappointing, and the want of agreement of opinions made one inclined to think that another extract from Plato was applicable. "For one certain sign that they do not know it, and that they do not know how to teach it, is, that they cannot agree about it among themselves." The confirmatory extracts that have been used in this book are therefore restricted for the most part to those about which there is a general agreement, or that describe some fact, and may be relied on, while other extracts which have been given as showing diverse views, must be taken as the reader chooses.

There is one cardinal point on which all the latest writers on electricity seem agreed, and that is the emission theory, and the author of the "New Physics and Whispers from an Old Pine," who says that sound is material, consequently claims them as cobelievers. When we were young we were told that emission was knocked on the head because it could not explain the polarization of light: how then does it explain the polarization of what are called electric waves?

In planning the arrangement of this book, the sealing-wax and paper business seemed so utterly void of anything from which a plain deduction could be made, that it was rejected as a starting-point and the voltaic experiment examined, and in this the chemical action in the cell gave so good a promise of relative meaning and need for explanation, that it was chosen as the subject for the first article of the book, and most happily, for without the lessons learned from the cell it is unlikely that any sensible conclusion could have been arrived at.

The study of this book has no doubt led its readers to conclude that electricity is a vibration of the æther associated

with the outside of the molecules of compound fluids, but the inconsistent opinions of the scientists of to-day as regards vibrations leave one somewhat dubious as to what vibrations really are and is one of the most puzzling things in scientific teaching. A sound from somewhere sets the air in motion and one of your lamp-shades rings a responsive note. An obliging scientist tells you that the air enclosed by the glass is of exactly that depth that is a measure or multiple of the wave-lengths of air that have come from the distant vibrating object, and that the glass responds in consequence: that the glass itself could of course produce no sound unless some force were spent upon it. And, he continues, this lovely December rose of yours is in the same way dependent for its colour on extraneous force: its molecules react with the light falling on it, some of it is absorbed by them and some of it is rejected, and the rosy hue you see is the rejected light mixed with light reflected from the surface. Then the flower does not produce its own colour? you ask. He looks at you with pitying superiority and says, It must receive light vibrations or remain unseen in form or colour. "There is no colour generated by any natural body whatever."

And yet he will tell you that these bodies produce vibrations of heat and electricity. That instead of being the inert things that their want of initiative as regards sound and light would lead you to suppose, that the molecules are all brimming over with self-created force, and that "a single pennyweight of hydrogen has in itself more energy than could be produced by burning fourteen chaldren of Wallsend cobbles": and that every molecule of every substance is composed of two equal antagonistic electricities which would immediately cancel each other anywhere else, but here are harmoniously blended till excited to emission in some way, and that the rest of the molecule is heat: and that this astonishing solid made of

motion, that cannot produce a single vibration of light, can for a thousand years produce vibrations of heat and electricity.

You murmur something *not for publication*, and wonder why that flower that is half hydrogen should smell so sweetly cool: and why, when we have been flooded with hydrogen in the form of rain, we should have had so abominably cold a summer: and why this particular scientist, a third of whose portly person must be hydrogen, should, when occupying the hearthrug, absorb heat instead of radiating it as scientific theory would lead one to suppose he ought to do.

Modern scientists do not seem to have gone in for the analysis of the elementary forces, and it is difficult to get any ideas for the purpose from modern scientific works. They are so much taken up with explaining complicated experiments to suit some dubious theory, and the experiments are done with such complicated contrivances in which mixed gases are worked on by refraction, reflection, rarefaction, electricity, magnetism, rays, radium, corpuscles, electrons, and nuclei, all mixed together and measured with artificial constants, that to ordinary intellects the result arrived at is about as convincing as the patter of a conjuror who smashes up a watch, puts it into a hat, and pulls out a white rabbit.

It is by the study of simple experiments that we can best hope to learn the origin of nature's forces: experiments in which that force alone is engaged which we want to study: and the author has tried to do this in this work, and the conclusion that the evidence has forced upon him has banished emission, and the immaterial electron, and the effusive corpuscle, to their sure natural abiding-place in the "equinoctial of Quebus, 91° from the poles." But he neither expects to make converts or friends by this, nor yet to stop the belief of others in mystical impossibilities.

Why should his disbelief in emission avail while it is still advocated by well-known authorities although the absurdity of it was clearly shown by Lord Kelvin.

* * * * *

There is a story told of Alexander the Great. He was encamped on the edge of a desert, and wishing to think alone, he wandered far into it: he came upon a skull which seemed to him such a remarkable skull that, taking it up and intending to show it to a philosopher who was in camp with him, he turned and went back. And as he went the skull became heavier and heavier till he could carry it no longer: so going to the camp he brought out the philosopher to see the skull, and pointed out to him how wonderful it was, and told him how astonishingly heavy it had become. "It is astonishing," said the philosopher, "but if you will put a little earth on the skull, it will become as an ordinary skull."

"Man goeth down to the pit and all his thoughts perish."

No thoughtful man, scientist or other, wishes to think, that when earth to earth is dropped over his skull and it remains to become "no more than foul mould," that all the splendid thoughts that once filled it are not even dissipated in space but are nowhere: so to preserve the thoughts collected in this work and to give them a chance of continuance, the author has decided on printing a hundred copies which he will give to those scientists whom he hopes may take an interest in his deductions: and if they would in kindness point out any *clear* experimental proof that disproves his deductions, he will be thankful, and if they will send him a word of encouragement he will be eternally grateful.

His principal reason for so restricting the publication is reviewers. No book, except the indecent novel, sells

if the reviewers do not praise it, and they praise nothing that is new unless it is by some one notorious. Reviewers have always been the bane of independent thought. If there had been reviewers in Adam's time we might have been going about in his fig leaves now. "A reviewer kept back the advancement of science, as advocated by Young, for half a century or more." What! says the reader, is he comparing himself to Young? Not a bit, neither is he comparing the modern reviewer with Brougham. *He* was an exceedingly clever lawyer, quick to see a weak point and to make full use of it, bitterly sarcastic and over bearing, and a clever writer, but, although he was a President of the Royal Society, he knew nothing in science except what was told him, and could not see into that beyond the end of his peculiarly flexible nose. In science he was an exemplification of echo—*vox et prœteria nihil*—and modern reviewers are exact copies of him in that respect: they are superficial copyists who only echo the last most startling cry, and the amount of original know ledge that they possess is like King Shrovetide's robes—"nothing before and nothing behind with sleeves of the same."

The writer has guarded his statements in most cases by opinions of famous scientists, and these would be as stumbling-blocks to the reviewers in any attempt at particular criticism, so they would fall back upon unguarded expressions, or misspelled words, or ill-arranged sentences, and would condemn on generalities, for "on any argument they can many times by a slight, laugh over what they could never seriously confute." But the author wants none of such criticism and would say, "But if by error led astray, I chance to wander from the way, let no blind guide observe in spite I'm wrong who cannot set me right."

Investigation went *pari passu*, when necessary and possible, with the writing of this book, and the writer

tried to present his mind as a *tabula rasa* for the collection of facts, and each chapter was completed separately and without thought of what was to follow: but it is difficult to obliterate first impressions, and few people have an individual basis of knowledge; most learn by rote and few by reason: they were taught, and accepted what they were taught, and never try to verify their teaching: they follow the flock with a blind belief in authorities. Imagine an Irishman, brought up to believe that green is the purest of pigments, being told that it is a mixture of orange and blue: it will require much proof to convince him, and then compelled against his will, he will be of the same opinion still. Early teaching tinges our ideas, and in several places in this book has led the writer to the expression of premature conclusions: they have been allowed to remain and no change has been made in the original manuscript except the smoothing of a rough phrase, or the better wording of a paragraph to make explanation clearer, therefore these expressions (which the student should obliterate) are to be taken in the same way as the opinions of a witness, which the judge tells the jury, are not evidence: they are left as showing the tend and change of thought, and must not be quoted as being the present opinion of the writer, or in any way as confuting the final deductions.

The bias that the early teaching of disputatious subjects must produce, should make teachers very careful in their choice of subjects with which to store young minds. Childhood is very receptive and very retentive of ideas, and has little reasoning faculty: and there is perhaps nothing which helps more to success in life than a good memory which is never so well acquired as in childhood. The aim of education therefore should be to teach a child morality, and such subjects as require memory—history, geography, grammar, Latin, and foreign languages: and subjects that in addition to memory teach consequent

reason and facts about which there is no possibility of error—arithmetic, geometry, and music: while law, medicine, chemistry, engineering, and physics, should not be approached till youth has put off childish credulity and can consider with a discriminating mind what is told him. This is especially needful as to physics, for what chance would a youth have of sanity if he took as gospel in childhood many of those ideas which are now advanced by scientists and which must indubitably perish: such as, that because two bodies cannot occupy the same place, they must therefore repel each other when close together: that the æther is cogwheeled or vorticate: that atoms possess perpetual motion: or the planetary system of atoms: or the bombardment of gases: and many other vain fancies that it would be tedious to mention?

* * * * *

"When people are content to remain mere echoes of other men's opinions, or purveyors of ready-made politics or philosophy—why, they are afraid to think and inquire lest they should find truth unsettling."

This book took two years to write, and the printing of it has been further delayed by Albertus Magnus' worst demon, therefore any topical references must be understood as referring to the years 1908-10, in which years it was written.

INDEX

A

ACCUMULATOR, 179
Adams 75
Æther, 224, 227, 233, 246
Air, conduction by, 135, 209
— constitution of, 55, 210
Alloys, 90, 95, 114
Alternating currents, 199, 203
Amalgamation, 4
Angot, 267
Animal electricity, xl
Anions, 22
Anode, 6, 20, 27
Appendix, xliii
Arc light, 67, 114, 198, 230
Armstrong, 57, 85, 202
Arrhenius, 265
Atmospheric electricity, 183, xxxiii
Atomic weights, 90, 106
Attraction and repulsion, 148, 167, 169, 177, 190, 212
Aurora, xxxiv, xxxv
— connection with electricity and magnetism, 264, 273, 276, 277
— — with water vapour, 269, 276
— height of, 268, 271
— light, colour, and spectrum of, 267, 270, 272, 275, 278
— locality of, 269
— movement of, 270
— shape of, 268
— sound of, 267
— the gulf, 268
— theories regarding, 264, 273, 277
— time of, 270, 276

B

Benham, 258
Berzelius, 34
Bjerkness, 93
Bolometer, 113
Bone and Wheeler, 71, 98, 103
Brush discharges, xvii

C

Carbon, 114
Catalysis, 9
Cavendish, 314
Chemical change in conduction, 77, 84, 93, 100, 134
— combination, 8, 13, 19, 82, 211, 223
Clausins, 21
Clouds, 296, 300, 305
Coherer, 106, 235
Cohesion, 103, 122
Comets' tails, xli, xlil
Condensation, 260
Condensed air, 40, 97, 106, 111, 112, 161, 190, 192, 194, 201, 206, 210, 220, 235, 241, 244, 310
Condenser, 253, 180, 182, 216
Conduction, xi, xii, xiii, xiv, 157, 184, 192, 200, 204
— by air, vapour and gas, 77, 79, 117, 120, 131, 135, 192
— by condensed air, 98, 106, 112, 191
— by flames and heat, 77, 93, 96, 113, 158
— by fluids, 22, 87, 117
— by solids, 90, 111
— copper as standard, 92
— on surfaces, 91, 94, 103, 105
— theories of, 94
Conductors, 92, 111, 128, 300, 302
— non-metallic, 93
— surfaces of, 90, 96, 98, 104
Conservation of energy, 231
Contraction, 66, 249, 254
Convection, xxv, 78, 119, 122
Crookes, 84, 203, 247, 248, 249
Crosse, 258
Current, 2, 6, 9, 20, 25, 32, 83, 110, 116, 135, 209, 221, 246
— action of, 7, 29, 142, 218
— — on junctions, 64, 69
— — on wires, 94, 206

Current, alternating, 198, 203
— direction of, 6, 140, 163, 168
— inertia of, 72, 165, 182
— movement by, 193, 195, 198, 217, 223, 234, 247, 253, 305
— physical effect of, 34
— production of, 5, 10, 76
— requires a circuit, 5, 24, 204
— velocity of, 20, 194, 208

D

Dampier, 282
Daniell's cell, 14, 88, 129
Darwin, 1, 283
Davy, 17, 44
Decomposition of water, 7
De la Rue, 129
Dewar and Fleming, 114
Diacathodic rays, 253
Discharge, xvi, xvii, xviii, 234
— by flame, 133, 158, 184
— by smoke and gases, 132, 301
— chemical action in, 129, 131, 133, 235
— colour of, 83, 123, 127, 135, 137
— from clouds, 299, 301
— from points, 120, 126
— in vacuum tubes, 82, 137, 246
— light of, 123, 128, 141
— noise of, 142
— positive and negative, 124, 128, 135, 140
— track of, 130
Dissociation, 19, 21, 25, 86, 137
Double refraction, 218
Dry Pile, 39
Du Bois-Raymond, 314
Dust, 82, 120, 122, 183, 191, 259, 284, 298, 301

E

Earth currents, 170, 183, 261, 273
Effusion, 70, 78, 104, 200
Electric dissociation, 19, 25
— mortar, 142
— motion, 23, 31, 137, 246
— preference, 15, 17, 87, 222
— smell, 135
— spark, 129, 135
— striæ, 138
— whirl, 120, 122
— wind, 119-123
Electrical machine, 46, 54, 224
Electricity, xxvi, xxvii, xxviii, xxix
— and friction, 46, 50, 58, 81
— compared with heat, 119, 223
— dissipation of, 119, 208
— is motion, 24, 31, 138, 195, 197, 246
— positive and negative, 138, 156, 199, 225, 299, 307
— production of, 10, 27, 47, 62, 261
— requires fluid or vapour for conduction, 58, 100, 108, 116
— residual, 184
— single or double, 135, 140, xxix
— speed of, 20, 194, 209
Electrochemical action, 3, 9-17, 24, 53, 61, 72, 82, 123, 129, 132, 134, 179, 195, 198, 204, 207, 235
Electrodeposition, 41
Electrodes, action at, 11, 27, 128, 133, 135, 143
— — of heat on, 136
— shape of, 128, 133, 139, 247
Electrolysis, 6, 19, 24, 40, 76, 87, 89, 100, 105, 108, 141, 143, 151, 156, 161, 163, 185, 198, 201, 210, 216, 224, 305, 312
— and effluves, 69, 78, 104
— in air and gases, 77, 117, 135
— theories of, 8, 20
Electrometer, 80
Electromotive force, 25, 88, 90, 110, 116, 122, 129, 137, 143, 151, 156, 161, 195, 220, 234
Electrons, 200, 208, 212
Electroscope, 77, 147
Elements, 12, 40, 89, 93
Emission, 197
Encke's comet, 323
Energy, 23, 26
Evans, 91
Evaporation, 259, 297
Exhaustion, 250
Expansion by electrolysis, 88, 142, 307, 309
Experiments connected with air skin, 51, 97, 105, 236
— atmospheric electricity, 257
— conduction, 84, 91, 96, 258
— convection, 187
— discharge, 49, 120, 130, 136, 184, 199

Experiments, electrolysis, 142, 217, 224, 246
— electromotive force, 224, 228
— heat, 103, 113, 136
— induction, 162
— influence, 145, 158, 213, 216, 221, 235, 237
— ions, 82
— molecules, 56, 70, 95, 104, 249, 252
— static electricity, 47, 54
— thermoelectricity, 62, 71
— ultra-violet light, 200
— vacuum tubes, 137, 172, 253
— voltaic electricity, 3, 18, 34, 76
— water skin, 107, 236

F

Faraday, 20, 58, 104, 125, 197, 212
Fireballs, xxxvii
Fitzroy, 284
Flammarion, 254, 203
Forbin, 281
Force, S., 65
Franklin, 153, 228, 259
Friction, 46, 50, 58, 61

G

Galena, 64, 76
Galvani, 46
Galvanometer, 63
Gases, electric action in, 78, 100
Geissler's tubes, 137, 172, 277
Globe lightning, 290
Glow discharge, 123
Goldhammer, 251
Goldstein, 254
Gravitation, 26, 29, 279
Grotthuss, 8, 20, 21
Gymnotus, 311

H

Halley, 317, 319, 323, 326, 329, 330
Heat, action on electrodes, 136
— and discharge in air, 131, 138
— compared with electricity, 144, 223
— effect on solids, 95, 98, 185, 207
— from current, 34, 206
— from resistance, 111, 113
— in circuit, 5, 64, 99, 112, 206
— and conduction, 77, 93
Heat of discharge, 141
— of metallic junction, 62, 64, 66, 69
— production of, 50, 66, 72
Hertz, 240
Hertzian waves, 150, 239, 243
Hittorf, 84
Hopkinson, 85
Humboldt, 314

I

Ignis fatuus, 285
Incandescent lamp, 91
Induced currents, 162, 165, 169
Induction, 125, xxii, xxiii
— coefficient of, 176
— of materials, 174, 176
— storage by, 177
— waves, 167, 171, 224, 235, 239
Inertia, 24, 72, 140, 165, 182, 201, 208
Influence, xix, xx, xxi, xxviii
— action of, 158, 160, 212, 218, 221, 239
— and atmospheric electricity, 263
— charge by, 145
— compared with heat, 144
— conveyed by æther, 148, 157, 235
— machine, 148
— the same as electromotive force, 161, 220
— vibrations, 148, 151, 154, 235
Insects, light of, 315
Insulation by gases, 78
Interference waves, 171, 294
Invar, 95
Ions and ionization, 20, 78, 80, 86, 89, 91

J

Jaumann, 251
Junctions, action of current on, 62

K

Kathions, 22
Kathode, 6
— stream and rays, 247
Kelvin, 85, 215, 259, 340
Kinetic energy, 166
Kolbe, 226
Krypton, 275

L

Langley, 114
Larmor, 239
Lebedeff's wave chart, 246
Le Bon, 70, 154
Lemstrœm, 271
Lenard, 247, 249
Leyden jar, 149, 180, 184, 199, 216, 225, 227, 235
Light, 233
— effect of, 75
— of discharge, 130, 141
— — in vacuo 138
— of incandescent lamp, 114
Lightning, xlviii, xlix, 87
— attracted by metal, 303
— conductors, 300, 302
— depilation by, 308
— light of, 300, 309
— physiological effect of, 87, 306
— protection from, 309
— return shock, 307
Lines of force, 173, 212
Liquid air, 54
Lodge, 23, 211
Luminous material, 332

M

Magnesium flame, 158, 200
Malepterurus, 314
Marconi, 242, 243, 244
Maxwell, 168, 184, 243
Medium round conducting wires, 94, 167, 209
Metals, action of heat on, 64
— — of impurities in, 66
— as conductors, 90
Molecular action in discharges, 120, 128, 137, 140
Molecules, 8, 14, 55, 107, 157, 185, 218, 227, 237, 244, 252, 298, 306
— action of current on, 88, 195, 218, 227
— and heat, 66, 233
— effect of exhaustion on, 250
Motion and matter, 197, 222
— conduction of, 196

N

Napoleon, one metal cell, 12
Nerve action, 36
Nipher, 199
Nonconductors, xiv

O

Oscillation of spark, 166, 182, 239, 305
Oscillator, 199, 240
Osmosis, 17
Otto von Guerick, 46
Oxyhydrogen flame, 66

P

Pettier effect, 64
Physiological effect of current, 37
Poggendorf, 32
Polarization, 12
Polarity, 164
Porous partitions, 14, 17
— substances and electricity, 56
Potential, 11, 18, 25, 40, 52, 71, 256, 261
Pressure, action of, 79, 131
Prolith, 289
Protoplasm, 280

Q

Quetelet, 262

R

Rain, 298
Rarefaction, action of, 125, 131, 139, 246
Rayleigh, 112, 299
Rays, xxx, xxxi, xxxii, 83, 201
Residual charge, 184
Resistance, xv, 7, 33, 72, 79
— and heat, 72, 111
— increased by alloy, 92, 114
— of fluids, 117
— of gases, 117
— of solids, 112, 114
— of wire conductors, 110, 112
Resonator, 240
Return shock, 149, 307
Richmann, 258
Righi, 239, 242, 294
Röntgen, 246, 250, 252

S

Saussure, 283
Schuster, 77, 301
Sebeck, 62

Selenium, 67, 75, 98
S. force, 65
Shackleton, 268
Smoke, conduction by, 77, 302
Spark discharge positive and negative, 135
— oscillating, 166, 182, 239, 305
— size of, 131, 141, 310
Static electricity, vii, viii, 34, 141
Stationary waves, 138, 162, 171, 226
Steam electric engine, 57, 202
St. Elmo's fire, xxxvi, 123
Storage, xxiv, 167, 176
Strain, 29, 153, 182, 190, 216, 225, 307
Striæ, 138
Submarine cables, 181
Sun, 265, 278, 326, 330, 332
— and electricity, 16
— rays, 321, 326, 329
Surfaces of fluids, 107
— of solid conductors, 90, 98, 104

T

Tait, 157
Thermoelectric force S., 64
— potential, 71
— welding, 72
Thermoelectricity, ix, x
Thermopile, 41, 62
Thompson, Silvanus, 36, 66, 78
Thomson effect, 64
Thunder, 309
Torpedo, 312
Torricellian vacuum, 138
Tourmaline, 74, 76
Transparency, 244, 252
Trowbridge, 226
Two electricities, 224, 228

U

Ultra-violet light, 77, 200, 235

V

Vacuum, 77, 130
— tubes, 105, 137, 246, 249, 277
— — chemical action in, 82
— — conduct on surface, 84
Vanderfliet, 154, 210
Volcanic electricity, 60
Volt, 301
Voltaic action in thermoelectricity, 76
— cell, 3, 6, 9, 17, 19, 24, 193, 217, 224
— — of one metal, 12
— cells, arrangement of, 32
— electricity, ii, iii, iv, v, vi, 142
— pile, 39, 217, 225
Volta's theory, 39

W

Water as conductor, 88
— composition of, 8, 29, 218
— decomposition of, 7
— drops and electricity, 237, 299
— skin, 107, 236, 298
— vapour, 192, 297
Weather, 256, 296
Wheatstone's revolving mirror, 128, 139
Whetham, 9
Wiedman's rays, 254
Wilson, 83
Wire screens, 154
Wollaston, 54

X

X rays, 250

Z

Zamboni, 39
Zeeman effect, 218
Zodiacal nebula, 319, 321, 325, 326

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